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714.

(Vol. XXXII.—July, 1894.)

CHAUTAUQUA, N. Y., SEWAGE DISPOSAL WORKS.

By WILLIAM B. LANDRETH, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

Chautauqua, N. Y., is a well-known summer resort on the southwest shore of Chautauqua Lake. The grounds run over a mile along the lake shore, and extend back from the lake for half a mile. There are about 10 miles of streets and avenues through which water pipes were laid several years ago.

Prior to 1893 the sanitary arrangements of the grounds were very crude. Public crematory closets were placed at various points, and cesspools were largely used as a means of disposing of the kitchen wastes. The rough garbage was drawn to the southern part of the grounds by the authorities, dried and burned. The cost of those methods of disposal was $2 000 for the season of three months, and the results were very unsatisfactory. A complete system of separate sewers was designed by Samuel M. Gray, M. Am. Soc. C. E., and built during the fall and winter of 1892 and 1893, under the direction of Thomas McKenzie, Jun. Am. Soc. C. E., as Engineer in Charge

for Mr. Gray. The sewers are from 8 to 20 ins. in diameter, with manholes at changes of grade or line, and no flush tanks.

Most of the grades are steep, and the large number of automatic public closets furnish the necessary flushing.

The main sewer extends nearly to the southern limit of the grounds, where it is 5 ft. above the mean lake level and 200 ft. from the shore. The question of the disposal of the sewage presented the problem of providing a means of purification that would prevent the slightest contamination of the lake, the purity of whose waters have been protected by rigid State laws.

The depth of the sewers and the steep slope of the hill side at its end prevented the use of any method of land filtration, leaving the only choice to some chemical method.

In October, 1892, the Assembly authorities advertised for plans and bids for erecting a complete system of sewage disposal, each plan to be accompanied by a bid for building the works in accordance therewith. The plan and bid submitted by the writer was accepted by the Trustees of the Assembly at their annual meeting in Pittsburgh, Pa., January 17th, 1893, and, after some changes suggested by Mr. Gray had been made in the plans, the contract was signed for the erection of the works.

Work was begun April 1st, 1893, under the supervision of Mr. Thomas McKenzie, Resident Engineer, and the plant was in operation the first week in July.

General Plan.—The works as built consist of a machine house, 40 x 40 ft., and four precipitation tanks and the necessary machinery for handling the chemicals and sludge.

The sewage enters the machine house on the west side in a brick channel 24 ins. wide, with a circular cross-section on the bottom. A screen made of iron bars, 1¼ x ¼ ins. spaced ¾ in. apart, set in the channel, catches all of the larger particles, which are raked off and burned under the boiler.

Two wooden chemical mixing vats, holding 850 galls. each, provided with revolving arms, are set near the inlet channel, to which they are connected by 3-in. iron pipes. The first vat contains milk of lime, for which the lime is slaked in a small vat suspended over it. The second vat contains a solution of sulphate of alumina, which is formed from crystal alum. The chemical pipe from each vat is pro-

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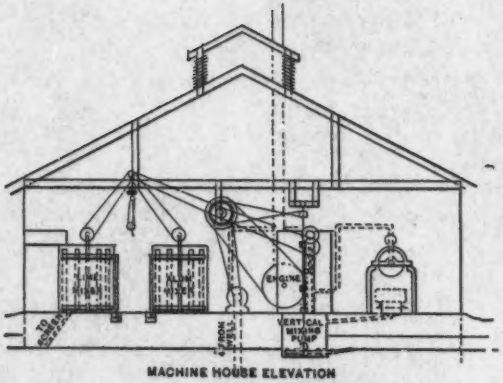
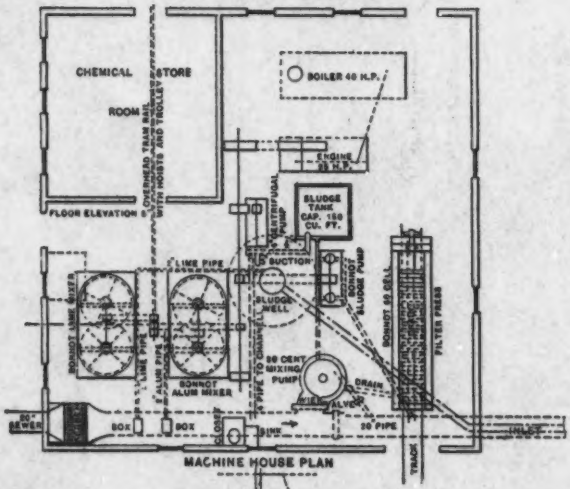
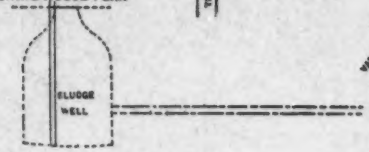


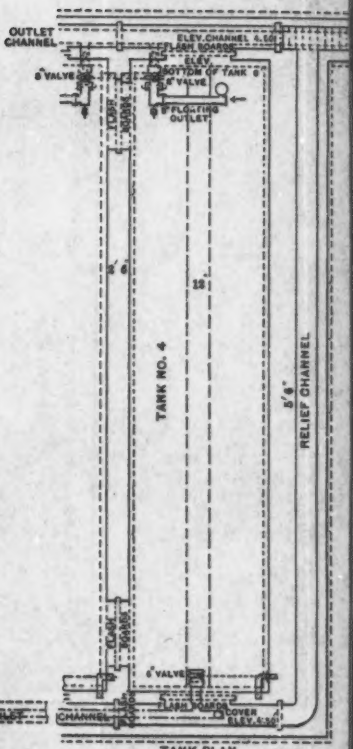
MACHINE HOUSE ELEVATION



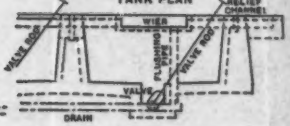
MACHINE HOUSE PLAN



SIDE ELEVATION AND SECTION



TANK PLAN



INLET END SECTION AND ELEVATION

PLATE I.
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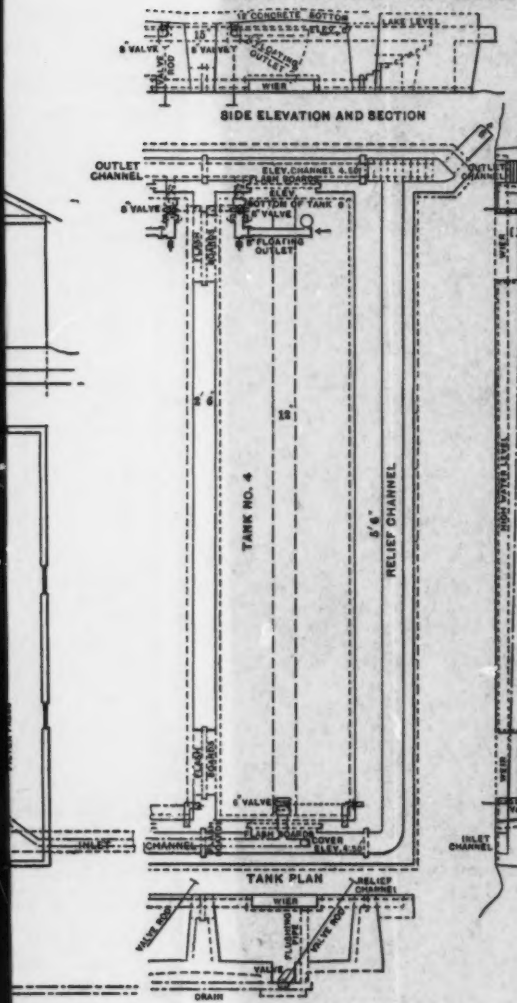

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A SEWAGE DISPOSAL.

vided with an iron box at the channel end, from which the solution flows into the inlet channel over a measuring weir 4 ins. wide.

The quantity of solution passing into the sewage over the small weirs can be determined very quickly by noting its height on a scale at one end of the weir, and the proper amount necessary for the sewage flow easily regulated.

After receiving the chemicals, the sewage passes over a weir 2 ft. long, where it is measured, and enters a mixing well, where a vertical centrifugal pump thoroughly agitates it and throws it into the inlet channel again, thus insuring a perfect mixture of the sewage and chemicals. Passing along the inlet channel, the mixture enters the main channel of the tanks.

Tanks.—There are four tanks, each 12 by 56 ft. inside, with 4½ ft. depth of water. The walls are of stone masonry laid in natural cement, lined with 8 ins. of hard brick laid in Portland cement, and are capped with sawed sandstone flagging 3 ins. thick. A main inlet channel extends along the end of the tanks, and carries the sewage into any of them over weirs 6 ft. long; and a similar outlet channel along the other end of the tanks discharges the effluent over steps into a 15-in. outlet extending into the lake. The end walls are 4 ft. on top and 5 ft. at the bottom; the side walls 2 ft. on top and 3 ft. at bottom, and the partition walls are 2 ins. thicker.

The tank bottoms are of concrete 12 ins. thick, made of 1 part of natural cement, 2 parts of sand, and 3 parts of broken stone; they slope from the sides with a fall of 1 in 30 to a central sludge channel 2 ft. wide, which has a fall of 2 ft. 6 ins. in the length of the tank to the sludge outlet.

A 15-in. low level outlet pipe is built in the outlet end wall, and is connected with each tank by an 8-in. iron pipe, which is fitted with a Ludlow valve and a galvanized iron hinged outlet pipe, the mouth of which is kept just under the surface of the water by a float. The several weirs and flash boards are so arranged that the tanks may be run in series or intermittently, as may be desired.

A relief channel runs along the outside of the last tank, allowing the night flow of clear ground-water to be run directly to the outlet, it having been found that the night flow stirs up the sewage already in the tanks, preventing settlement.

Method of Working.—When any tank is to be cleaned, the sewage is

cut out of it by the flash boards, and after a rest of about an hour for settling the sludge, the outlet valve is opened and the effluent drawn off till the sludge is reached. The outlet valve is then closed, and a sludge valve at the foot of the sludge channel opened, when the sludge flows through an 8-in. sludge drain, built in the inlet wall of the tanks, to the sludge well.

The sludge well is 16 ft. deep, 8 ft. in diameter, with brick walls 12 ins. thick, and is fitted with an iron manhole cover in the machine house floor. The sludge is pumped from the sludge well by a 4-in. Van Wie centrifugal pump into a sludge tank set on the machine house floor, holding 150 cu. ft. The sludge is allowed to settle in this tank and the clear water on top is drawn off by a skimmer pipe, added since the completion of the works. When ready for pressing, the sludge is forced into a 60-cell filter press by a power pump having two solid plungers and ball valves made of hard rubber, flat valves having proved a failure. The valves are easily accessible, the chambers being fitted with detachable covers.

The press has 60 steel chambers 30 ins. in diameter, with a 4-in. hole in the center of each, forming a continuous passage from end to end of the press.

A coarse jute sack is suspended between the chambers, which are faced with rubber, to prevent the cutting of the sacks or squirting of the press liquor. The chambers rest on the frame of the press on small wheels, and are held in contact with each other by pressure applied by a screw and hand wheel at the end of the press.

When the sludge is forced into the end of the press, the water passes out between the chambers along small channels in the lower faces of the cells and through the longitudinal meshes of the sacking, leaving the coarser particles of sludge between the faces of the chambers of the press. When the press is full of sludge cake, the pressure gauge on it shows a pressure of about 60 lbs., that being the point at which the relief valve on the force pipe is set, and the water ceases to flow from the drips of the press. The press screw is released by a lock nut, a car run under the press and, as the chambers are separated from one another, the cakes fall into it, and, when full, it is run out of the building and emptied.

The cakes are 30 ins. in diameter and 1¼ ins. thick. When taken from the press they weigh 21 lbs., and when thoroughly dried the

PLATE II.
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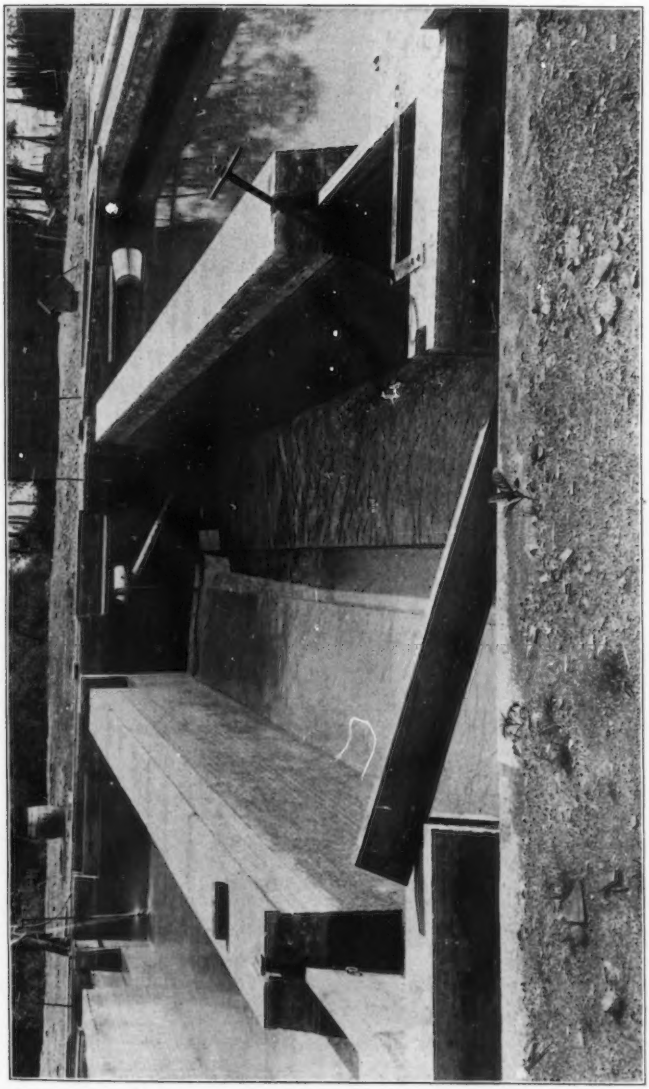

weight is reduced to 12 lbs., showing 43% of moisture in them when taken from the press.

The sludge has been used by the Assembly authorities and neighboring farmers as a fertilizer. The tanks were operated in series, after experiments had proved that the better method.

The works were operated from July 1st to October 1st, during which time the daily flow was from 125 000 to 150 000, with about 75 000 galls. of ground-water.

The number of people using the sewers was from 3 000 to 7 000, with a probable average of 4 000; and from the water works pumping records the daily consumption of water was about 20 galls. per capita.

Profiles of gaugings show an hourly maximum of a little more than 6 % of the daily flow; while from midnight to 5 A.M. the flow was clear ground-water. During heavy storms considerable rain water entered the sewers, probably through holes in the manhole covers and from a few roofs.

Chemicals.—The lime used was the Lighthouse brand of Marblehead lime, from Sandusky, O., and its cost was 83.2 cents per barrel delivered at the works, or .416 of a cent per pound. The alum was in the form of white crystals, costing 2.15 cents per pound. During the 92 days that the works were in operation, 29 500 lbs. of lime, 6 400 lbs. of alum, and one barrel of copperas were used. Large amounts of chemicals, especially alum, were used during July, in experimenting, to determine the proper proportions necessary, and the cost of operation was increased thereby.

After the experimental period was passed, the amounts used daily were one barrel of lime, 30 to 40 lbs. of alum, and 2 to 5 lbs. of copperas.

Cost of Operation—Labor.—The men employed at the works were: One superintendent and engineer at $85 per month; one helper a part of the time, from 7 A.M. to 6 P.M., and a watchman from 6 P.M. till 7 A.M., each of whom received 12½ cents per hour. The total labor bill for 92 days was $386, or a little less than $4.20 per day. For the population of 4 000 this would give a little over one-tenth of a cent as the per capita daily cost of labor.

Oil, Chemicals, etc.—Fuel, oil and waste cost about 40 cents per day. The total cost of chemicals was $269 52 for the entire season, or an apparent daily cost of $2 87, but as large amounts of chemicals were

used in experiments in July, the cost per day of chemicals during August and September was probably about as follows:

One barrel of lime	$0 83
35 lbs. alum	0 75
3 lbs. copperas	0 12

making a total of $1 70 per day. On the above basis the total daily cost, after the experimental stage, would be: Labor, $4 20; fuel and oil, etc., $0.40; chemicals, $1 70, giving a total of $6 30. For an average attendance of 4 000, the daily capita cost would be .157 of a cent or $0.573 per capita per year, to which should be added an interest charge of $0.165, making a total per capita cost of $0.738 per year.

Chemical and Physical Results.—After July 28th, the effluent was uniformly clear and odorless. Samples of the sewage and effluent were taken at 4 P. M., September 25th, after the night flow had left the tanks, and were carefully sealed and sent to Prof. Maurice Perkins, Union College, Schenectady, for analysis. The samples were delayed in transit and did not reach the laboratory till September 29th, and on October 9th, Prof. Perkins reported as follows:

CHEMICAL LABORATORY, UNION COLLEGE,
SCHENECTADY, N. Y., October 9th, 1893.

Report of the results of the chemical analysis of a specimen of crude sewage and the effluent after treatment, received from W. B. Landreth, C. E., from Chautauqua, New York.

	Parts in 100 000.	
	Crude sewage.	Effluent.
Appearance	Turbid.	Clear.
Color	Light grayish.	None.
Odor	Urinous.	None.
Total solid residue	117	23.6
Mineral matter (after incineration)	59.2	14.4
Loss on incineration (organic matter)	57.8	9.2
Chlorine	6.0129	6.0129
Corresponding chloride of sodium (common salt)	9.97	9.97
Free ammonia	2.428	1.3568
Albuminoid ammonia	2.088	.4856
Phosphates	Strong reaction.	None.
Nitrates	Not detected.	Not detected.
Nitrites	" "	" "

MAURICE PERKINS,
Professor of Chemistry in Union College.

PLATE III.
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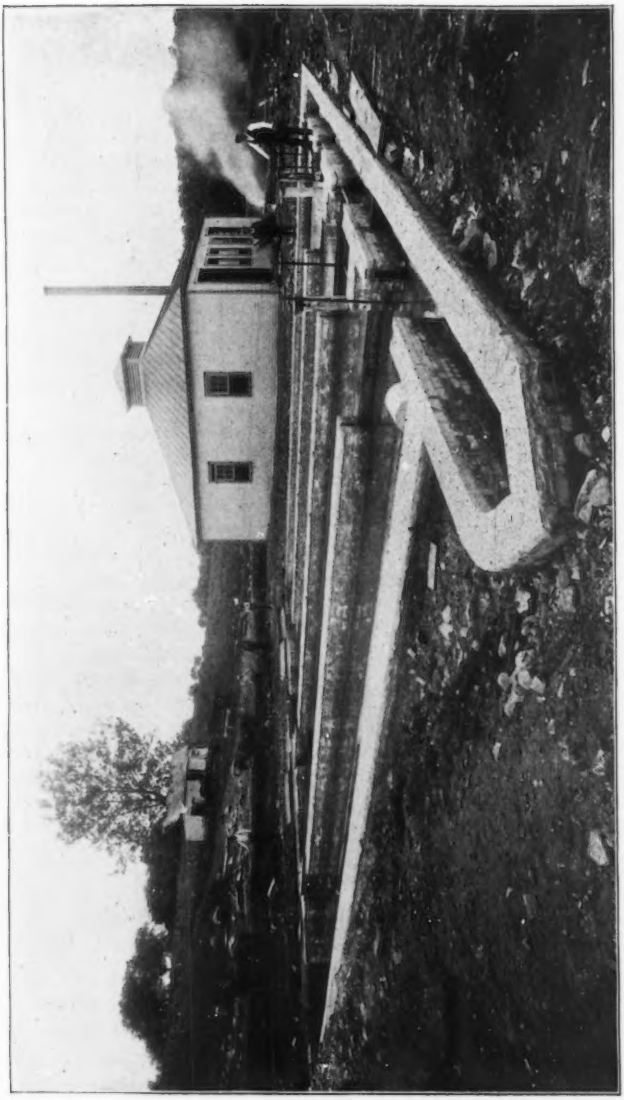

UNION COLLEGE,
SCHENECTADY, N. Y., October 9th, 1893.

WILLIAM B. LANDRETH, Jamestown, N. Y.

Dear Sir,—I have delayed reporting the results of the chemical analysis of the specimens received September 29th because I wanted to make some observations on them after standing some time.

The analyses were made as soon as possible after their receipt. To-day I made another partial analysis of the crude sewage. This was to explain some of the results of the first.

Let me first speak of the treated sewage or effluent. This is the first "effluent" that I have ever seen that did not undergo change, such as to make it muddy and smell badly. To-day though the bottle, half full, has been kept in the laboratory, at the ordinary temperature of a room at this period of the year, the fluid is as clear and to the senses as unoffensive as at the first moment of receipt. How thorough the removal of solids and putrescible matter has been you can see by the comparison of the two analyses.

The analysis of the crude sewage shows large quantities of free ammonia. Larger amounts of this than of the albuminoid were present, but in the effluent you will see there was much less ammonia. It would be difficult by any process to remove the ammonia from the crude sewage. So this found in the specimen sent me above that in the effluent must have been formed during the time which elapsed between its collection and my analysis (three days). When the reagents used in the process struck the original or crude sewage, nearly one-half of the nitrogen, which I found in the form of free ammonia, must have been in the albuminoid form and precipitated by them. Thus removed before the change had occurred.

The crude sewage contained some finely divided paper, which, of course, left an ash on incineration. This in part accounts for the high ash account of the crude sewage. But it is this as well as other materials which you desire to remove by your process.

In conclusion, if you can furnish such an effluent, I do not see how it can become offensive.

Respectfully yours,
MAURICE PERKINS.

The concentrated character of the sewage is shown by the total solid residue of 117 parts in 100 000, as might be expected from the low water consumption. The analysis shows that 80% of the total solids and 76.6% of the albuminoid ammonia were removed.

The writer is aware that the result shown might not have been obtained continuously and probably was not, and gives the analysis simply as that of one sample each of sewage and effluent. During the

present season daily examinations of the sewage and effluent will be made chemically and biologically by a careful and experienced observer, and measurements of the sewage will be taken by a recording gauge. The amount of pressed sludge produced was about 0.8 lb. per capita daily. The total cost of the works was $16 500, exclusive of the land, including 150 ft. of iron outlet laid on the bottom of the lake. The chemical mixers, sludge pump and sludge press were built by the Bonnot Company, of Canton, O., which also furnished and erected the shafting, pulleys and piping.

This description of the works and the results obtained are given simply as showing the way in which the problems presented were solved, and not as a guide for all cases, as the writer is fully aware of the limitations of chemical precipitation of sewage.

The results obtained seem to have been in part due to (1) the thorough mixing of the sewage and chemicals; (2) the careful gauging of sewage and chemicals and their proper proportioning, and (3) to the design of the tanks by which the course of the sewage is positive and the formation of cross currents prevented.

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(Vol. XXXII.—July, 1894.)

THE CIPPOLETTI TRAPEZOIDAL WEIR.

By A. D. FLINN and C. W. D. DYER.*

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

NOMENCLATURE.

A = area of vertical cross-section of water in canal of approach at point of measurement of H.

C = coefficient in formula for Q.

c = coefficient of contraction, according to Cippoletti; called by American authorities coefficient of discharge.

g = acceleration of gravity = 32.1644.

$$\sqrt{2g} = 8.0205. \quad \frac{1}{2g} = 0.01555.$$

G = depth from crest of weir to bottom of canal of approach.

* In preparing this paper the writers have made use of the following books and pamphlets: J. B. Francis, "Lowell Hydraulic Experiments"; Hamilton Smith, Jr., "Hydraulics"; Mansfield Merriman, "Treatise on Hydraulics"; L. G. Carpenter, "Bulletin No. 13, Colorado State College"; Cesare Cippoletti, "Canal Villoresi; Modulo per la Dispensa delle Acque"; Engineering *Record*, August 13th, 1892; *Transactions* of Am. Soc. C. E., Vol. XII, 1883, p. 55, Fteley and Stearns.

H = head measured by hook-gauge.

h = effective head.

h_a = head corresponding to velocity of approach.

L = horizontal distance from end of sill to the nearer side of the canal of approach.

l = measured length of sill.

M = leakage from canal of approach to Francis weir during an experiment.

q = quantity of water discharged during an experiment, as measured by the Francis rectangular weir.

$q' = q + M$. Q_1 = approximate discharge per second.

Q = discharge per second. $Q = \frac{q'}{t}$.

t = time in seconds.

V_a = mean velocity of approach. $V_a = \frac{Q_1}{A}$.

$e\,v\,h$ = extreme variation in head during an experiment.

$$h = H + b\frac{V_a^2}{2g} = H + b\,h_a.$$

$b = 1.4$ for weirs with full contraction.

$$\therefore h = H + 1.4\,h_a.$$

$$q = t \times \tfrac{2}{3}\sqrt{2g} \times 0.623\,(l - 0.2\,h)\,h^{\frac{3}{2}}.$$

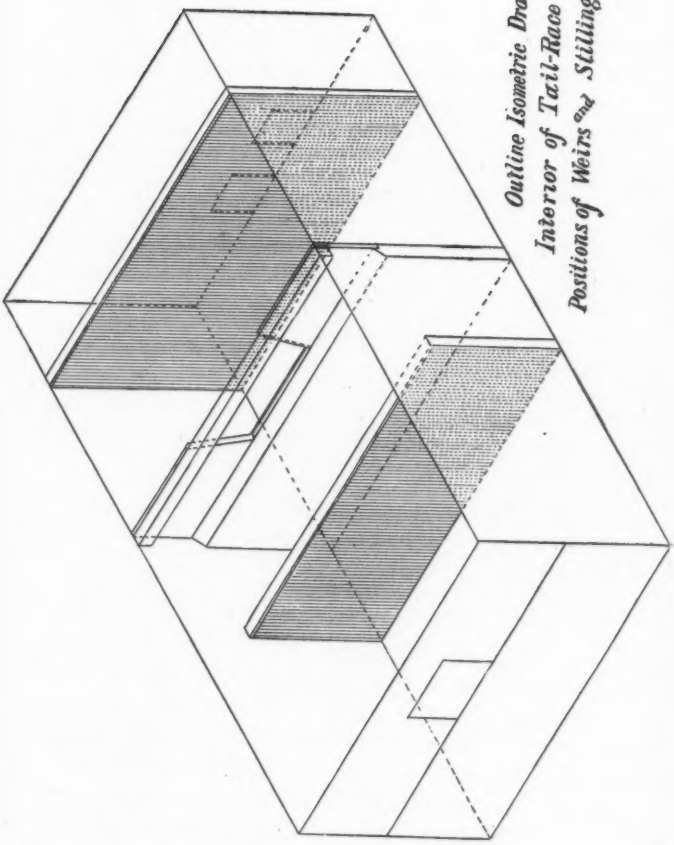
$$= t \times \tfrac{1.9}{3}\,(l - 0.2\,h)\,h^{\frac{3}{2}} \text{ (very nearly)}.$$

$$q_1 = t\,c\,\tfrac{2}{3}\sqrt{2g}\,l\,h^{\frac{3}{2}} = 5.347\,t\,c\,l\,h^{\frac{3}{2}}.$$

$$C = \frac{Q}{l\,h^{\frac{3}{2}}}.$$

$$c' = \frac{C}{\frac{2}{3}\sqrt{2g}} = \frac{C}{5.347}.$$

The Weir.—The weir with complete contractions was formerly considered to be the most accurate and convenient means for measuring large quantities of water. The form commonly used has been the rectangular weir with horizontal sill and vertical sides and with three complete contractions. With this form of weir, the coefficient of discharge is not constant, but increases with the length of the weir and diminishes when the head on the sill increases. Furthermore, because of the effect of end contraction, with equal heads, the quantities discharged are not proportional to the length of sill; and with constant sill length, the discharge does not vary proportionally to any power of



Outline Isometric Drawing of Interior of Tail-Race Showing Positions of Weirs and Stilling Backs.

the head, because of the effect of bottom contraction. These facts constitute objections to the rectangular weir. When the Villoresi Canal was projected in 1881, the government of the province of Milan, Italy, regarded these objections as sufficiently serious to make another form of module desirable. Consequently the engineer, Signor Cesare Cippoletti, was instructed to devise a module, based upon the theory of the weir, which should be free from these difficulties.

The problem which Cippoletti set himself to solve was to determine the conditions of a weir which would measure the discharge with an error, due to any one cause, not greater than $\frac{1}{2}\%$ and at the same time retain the simple formula, $Q = C\, l\, h^w$. He adopted the results of the Lowell experiments of Mr. J. B. Francis as the basis of his investigations, supplementing them with the works of some other hydraulicians, and with data from experiments of his own made for the purpose of discovering the effects of variations in certain details of construction.

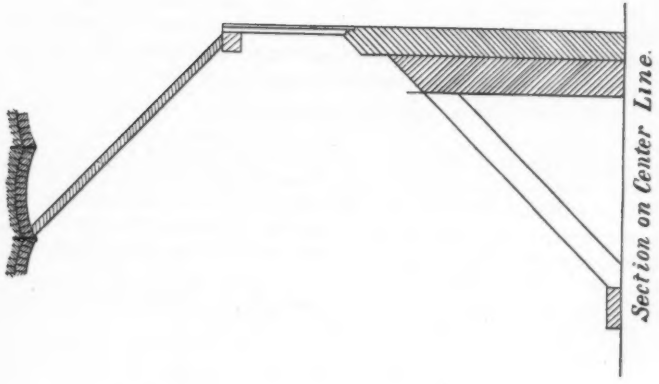
Commenting upon the variations of the coefficient of contraction in the Francis formula, Cippoletti says:

"The cause of such variation of the coefficients is easily revealed by the fact that, while in the common formula there is a single coefficient of contraction, the phenomenon is double, since there is proof of a superficial and a lateral contraction; and if the first is proportional to the breadth of the stream and is found to be represented in the formula, the second instead is proportional to the depth of the vein, and has no factor in the usual formula which takes account of it. From this it follows that the incomplete common formula is forced to represent also the variations of the discharge depending upon the varying depths of the vein; the coefficient of horizontal contraction is obliged to assume diverse values, while from its nature it would be constant. The questions hence reduce themselves to separating the two contractions and representing each in the equation of discharge by proper terms."*

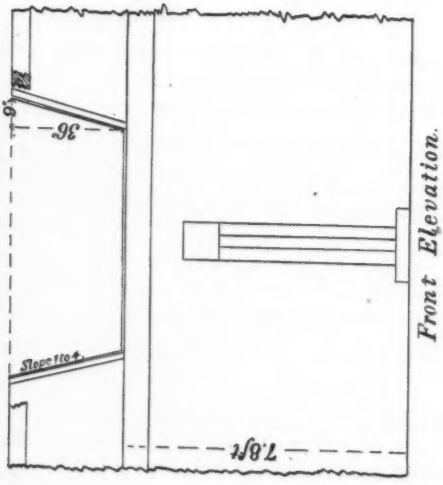
To overcome the difficulty here described, Cippoletti concluded to eliminate the effects of end contraction automatically by a modification in the shape of the weir. Instead of making the ends vertical as in the rectangular weir, he gave to them a slope of one horizontal in four vertical, as determined by the following mathematical deduction:

"Keeping in mind, as ascertained, that the effect of this (end) contraction is proportional to the depth of the stream, and equivalent to

* Translated from "Canale Villoresi," etc.



Section on Center Line.



Front Elevation.

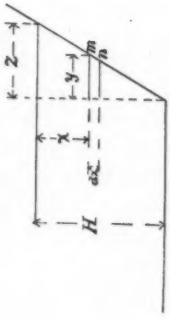


Figure A.

diminishing the breadth one-tenth of the depth, nothing prevents the ends of the weir, instead of being vertical, being inclined outward in such a way that the water which passes through the two triangles may compensate exactly, for each head, for the loss caused by the lateral contraction. This is equivalent to constructing a weir of trapezoidal form, in which the inferior base is assumed as the breadth, and the discharge is given by the common formula,

$$Q = c\, l \tfrac{2}{3} \sqrt{2g}\, h^{\frac{3}{2}},$$

in which, therefore, there came to be assumed for c the constant value of the horizontal contraction alone, found by Mr. Francis to be 0.623.

There remains to determine what should be the inclination to apply to the sides of the stream in order that the discharge through the two lateral triangles may be equivalent to compensating for the effect of the lateral contraction.

In Figure *A* (Page 13) let $m\,n$ represent an element at the depth x, below the surface; its area will be—

$$y\,dx = \frac{h-x}{h} \cdot z\,dx.$$

Its discharge will be expressed by—

$$dQ = c\frac{h-x}{h} \cdot z\sqrt{2gx}\,dx = c\frac{z}{h}\sqrt{2g}\,(h x^{\frac{1}{2}}\,dx - x^{\frac{3}{2}}\,dx).$$

Integrating—

$$Q = c\frac{z}{h}\sqrt{2g}\,(\tfrac{2}{3} h x^{\frac{3}{2}} - \tfrac{2}{5} x^{\frac{5}{2}}).$$

Taking this between the limits $x = h$ and $x = 0$, we have—

$$Q = c\frac{z}{h}\sqrt{2g}\,(\tfrac{2}{3} h^{\frac{5}{2}} - \tfrac{2}{5} h^{\frac{5}{2}}) = c\,z \cdot \frac{4}{15}\sqrt{2g}\,h^{\frac{3}{2}}.$$

From the other part of the Francis formula we have that the diminution of the discharge due to the effect of the lateral contraction on one side is as follows:

$$c \cdot 0.10\,h \cdot \tfrac{2}{3}\sqrt{2g} \cdot h^{\frac{1}{2}}.$$

For which reason the two quantities are equivalent, so that—

$$c\,z\frac{4}{15}\sqrt{2g}\,h^{\frac{3}{2}} = c \cdot 0.10\,h\,\tfrac{2}{3}\sqrt{2g}\,h^{\frac{3}{2}}\ ;\ \text{whence}$$

$$z = 0.25\,h.$$

That is to say, it is sufficient to construct the weir with the sides inclined at $\frac{1}{4}$ in 1, in order that for every depth of the stream the effect of the lateral contractions may always be compensated for by the water that flows through the lateral triangles, and, as we desired, without need of taking account of it in the formula."*

* Translated from "Canale Villoresi," etc., pages 37 and 38.

The conditions necessary to be fulfilled for this weir in order that no one cause may produce an error greater than $\frac{1}{2}$ % are the same as are usual for rectangular weirs with complete contraction. And the head should be read to within one-three-hundredth of the depth on the sill. The weir must not vary more than 4° from being perpendicular to the axis of the canal. From a study of causes of inaccuracies, Cippoletti concludes that Francis' coefficient should be increased one per cent. Hence, the formula for discharge for the trapezoidal weir becomes, in English units, assuming the coefficient of contraction to be, as determined by Francis, 0.623,

$$Q = 3.36\tfrac{2}{3}\, l\, h^{\frac{3}{2}}.$$

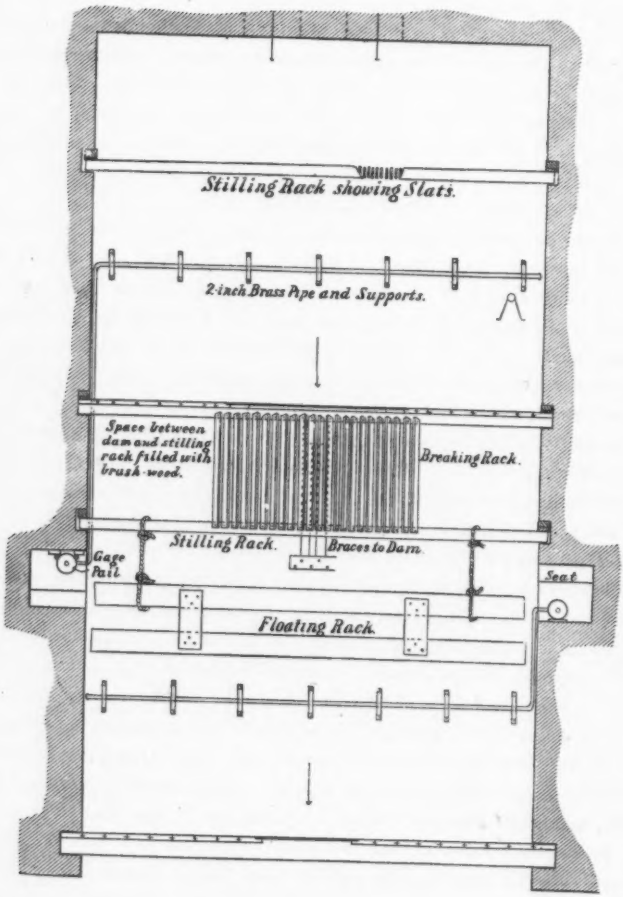
As far as the writers have been able to ascertain, the only experiments that have been made to test the reliability of this coefficient are those of Prof. L. G. Carpenter, of the Colorado State Agricultural College, on weirs 6 ins. and 12 ins. long, and a few laboratory experiments made during the winter of 1891–92, by Mr. T. McE. Vickers, with weirs 0.3 ft., 0.6 ft. and 0.9 ft. long, at Cornell University. Both these experimenters found that, within the limits of their experiments, Cippoletti's formula gave results not liable to an error of more than one per cent.

Thinking the field to be an interesting one for experimental research, the writers determined, if possible, to make some tests on a practical scale.

The Holyoke Water Power Company kindly granted them the use of their testing flume, and thus afforded as good conveniences for such a series of experiments as they have conducted as could probably be had anywhere, except at very considerable expense.

The Flume and Apparatus.—The flume at which the experiments were conducted is situated on the north side of the second level canal of the Holyoke Water Power Company, Holyoke, Mass., and is used by this company to test water wheels. The building was erected in 1881, under the direction of Clemens Herschel, M. Am. Soc. C. E.

The whole structure rests on a good foundation of piles. Water is admitted to the building through a flume 9 ft. in diameter, and from the receiving reservoir, flows through two gates into the wheel pit, whence it passes into the tail-race, where the experiments were conducted, and thence out into the canal, over the rectangular weir used by the Water Power Company.


Stilling Rack showing Slats.
2-inch Brass Pipe and Supports.
A
Space between dam and stilling rack filled with brush-wood.
Breaking Rack.
Stilling Rack.
Braces to Dam.
Gage Pail
Seat
Floating Rack.

The same difficulty presented itself here that has been encountered in all weir experiments of any magnitude, except those of Mr. J. B. Francis and Messrs. Fteley and Stearns, that of having a basin large enough to measure the water. It was impossible in this case to have a basin of more than about 2 400 cu. ft. capacity; besides, no by-pass could be arranged for the waste water, and so it was decided to make the quantity measurements over the rectangular weir of the Water Power Company. This weir was set with great care, and complies with all the requirements determined by Mr. Francis. Hence the writers feel satisfied that measurements made with it may be relied upon as reasonably accurate.

The basin in which the two weirs were set is 35.5 ft. long and 20 ft. wide, of constant cross-section.

The walls and bottom are covered with cement, making them very nearly water tight. The weir on which the experiments were made was placed 19.2 ft. back of the rectangular weir, and was set in a temporary dam of dry spruce timbers 21 ft. x 8 ins. x 8 ins., the ends of which were built into the wall on either side. The top timber of the stationary part of the dam was beveled at an angle of 45° and was grooved at the up-stream edge on top so as to receive the lower ends of the weir boards, which were 36 ins. high, 12 ins. wide, and 2 ins. thick. These were made water tight by mortising each and driving in a spline of well-dried white pine between adjoining boards. The up-stream face of the dam was a vertical plane, perpendicular to the axis of the basin. The dam was well braced at the center in front by an upright timber 12 x 12 ins., which was shored to a cleat in the floor. The weir boards were held in position by a 6 x 6-in. timber placed horizontally 3 ft. above the sill of the weir and securely braced against the roof, which is made of I beams and masonry because the tail-race extends under a spur freight track.

The sill and sides of the weir were made of ⅜-in. wrought iron beveled 45° to 0.1 in. and carefully countersunk into the up-stream face of the dam. The sill piece was 10 ft. 6 ins. x 5 ins.; the two side pieces 3 ft. x 3 ins. All three presented clean, sharp edges to the water. Each side piece was fastened to its weir board by three screws passing through three slots, and thus giving opportunity for accurate adjustment to the proper inclination. A stilling rack was placed 11 ft. back of the trapezoidal weir, and another 13 ft. 6 ins. back

of the rectangular weir, to direct the threads of water parallel to the sides of the basin. These racks were made of boards $\frac{7}{8}$ x 6 ins. x 8 ft., beveled to a feather edge on the down-stream side, and placed vertically $1\frac{1}{2}$ ins. apart.

The two hook-gauges used, one of the Emerson and one of the Sawyer pattern, read by vernier to 0.001 ft., and the nearest, 0.0005 ft., could be estimated readily. They were placed in two recesses in the walls, one on either side of the basin. Each gauge was securely screwed to a block 20 x 6 x 2 ins., which in turn was firmly fastened to the masonry wall by two $\frac{1}{4}$-in. bolts. The recesses are large enough for a man to sit in comfortably in order to take the gauge readings. In one is an electric bell which strikes every minute or half minute, according as the clock may be set with which it is connected. This recess is also connected by a speaking tube with the room in which the gates are regulated.

The heads (H) were measured in metal pails which were connected with the tail-race in the following way: Six feet back of each weir, parallel to it, and 1 ft. above the bottom of the tail-race, there was placed horizontally a 2-in. brass pipe, the under side of which was perforated with a row of holes $\frac{1}{2}$-in. in diameter, 2 ins. apart. At one end, this pipe was connected by a quarter-bend to a straight pipe leading along the wall of the tail-race to the hook-gauge recess. This latter pipe was connected by a piece of rubber hose to the bottom of the hook-gauge pail, thus allowing the pail to be raised or lowered, so as to keep the water surface always near the top of the pail. The pails were hung on special racks fastened to the wall. This arrangement added materially to the convenience and accuracy of observation. Before the experiments were begun, steam was blown through these pipes, to clean out any dirt that might have collected in them.

With the sills set at $l = 4$ ft., the first stream of water was let into the tail-race. The wicket in the dam of the trapezoidal weir was left open so that both basins could fill at the same time, thus relieving the pressure on this dam. When the basins were nearly full, the wicket was lowered and the water was soon pouring over the trapezoidal weir with a head of about $\frac{9}{16}$ ft. The effect which this vein produced upon the water in the lower basin was anything but pleasing. The stilling rack seemed to have only a slight effect upon the stream; the water boiled up as from a small cataract; whirlpools and eddies were to be

found everywhere in the lower basin, and back currents could be plainly seen within 2 or 3 ft. of the ends of the rectangular weir. Before any experiments could be made it was necessary to break the force acquired by this vein from a free fall of nearly 2 ft. to the surface of the water in the lower basin.

First of all, narrow strips were nailed across the backs of the vertical pieces of the stilling rack, making a sort of sieve of it with meshes about 1½ ins. square. This did not have the desired effect, although there was a slight change for the better. The next remedy tried was placing slats 3 ins. x ⅞ in. x 6 ft. parallel to the axis of the basin from just below the sill of the trapezoidal weir to the top of the stilling rack in front (Page 16). These slats were set edgewise, about 3 ins. apart, with one corner uppermost, so that their sides made an angle of about 45° with the horizontal, sloping each way from the center of the weir, so as to break up the vein and throw the water toward the sides of the canal. They were placed far enough below the sill (0.6 ft.) not to interfere with the discharge. Quite a marked effect was produced in this way; but, as yet, the condition of the water in the lower basin was not satisfactory with heads over $\frac{5}{16}$ ft. Upon the suggestion of Mr. A. F. Sickman, hydraulic engineer for the Water Power Company, the space between the dam and the stilling rack was filled with brushwood, and boards were placed against the up-stream face of the rack so as to extend across the basin, and from a few inches above the water surface to 1 ft. or 1½ ft. below it. All these devices, together with a floating rack, a few feet from the down-stream side of the vertical stilling rack, produced the desired effect, a perfectly smooth surface and hardly any velocity of approach, for heads up to about 1 ft.

The floating rack consisted of two 3 x 12-in. planks, about 3 ft. apart, extending across the basin, parallel to the weir and held in position by ropes.

The water approaching the trapezoidal weir, throughout the experiments was uniformly in perfect condition, without the slightest sign of an eddy or cross-current. This excellent result was due to the large area of cross-section of the canal of approach (the width being 20 ft. and the depth below the crest of the weir nearly 8 ft.), and to the method of admitting the water (described above). Some annoyance was experienced at first from the leaking of the timber dam in

which the trapezoidal weir was set. When the two basins were filled with water, an additional load of about 155 tons was brought upon the foundation, and caused a slight temporary settlement, owing to the fact that the flume rested on piles driven into soil infested with quicksands. When the water was removed, the floor returned to its former level. This action caused some of the joints of the dam to open a little, especially the one between the bottom timber and the next timber above; the bottom timber, being cemented to the floor, rose and sank with it. To overcome this difficulty, the timbers were more securely bolted and nailed together and to the center post in front, and the joints were carefully puttied. But, although these helped, they were not a sufficient remedy, because they had to be applied when there was no water in the basins, and then the joints were tight. Something must be applied which would take up the slight motion caused by the settlement of the floor. Finally, Mr. Sickman proposed, as a cheap and probably effective expedient, that strips of enamel cloth, such as is used for covering table tops, be tacked over the joints on the up-stream face of the dam in such a way as to allow for the vertical movement and yet be water-tight along their edges. This plan proved completely successful, and after the application of the enamel cloth there was no noticeable leak from the upper basin.

The Experiments.—In all, 39 tests were made, ranging from a head of 0.3 ft. on a 3-ft. sill to a head of 1.25 ft. on a 9-ft. sill. Lack of time and the limitations of the apparatus prevented us from further extending the scope of our experiments. The results of the first seven tests cannot be used, because, as was discovered during the seventh, the temporary dam still leaked; hence the data from these were thrown out, since, owing to the arrangement of the water passages from the wheel pit to the tail-race, this leakage could not be measured. At the close of the seventh experiment, the enamel cloth was applied to the dam, as mentioned above, and during the remaining 32 experiments, there was no leak through this dam.

With a few exceptions, the duration of an experiment was ten minutes, eleven readings of each hook-gauge being taken. One observer, throughout the experiments, took the heads upon the rectangular weir with the Emerson gauge; the other observed the heights on the trapezoidal weir with the Sawyer gauge. The electric bell was set to

strike once a minute. In each experiment, the water was allowed to run until it was ascertained by taking several readings of the gauges that the flow was quite steady. Then, at a given signal, we began to record the gauge readings at each ringing of the bell. By means of the excellent arrangement of gates, the depth of water on the sills of the weirs could be very closely adjusted and well controlled. Only at certain hours of the day, when the large mills were starting up or shutting down, was any trouble experienced in maintaining a reasonably constant head.

In studying the records of the gauge readings, it was noticed, in the cases of some experiments, that by omitting one or two readings at the beginning, or at the end, or both, a consecutive list of heads could be obtained which had a much smaller extreme variation than was given by the whole eleven readings. Examination showed that the greater variations in the cases of the rejected readings, as well as in some other experiments, were probably caused, in most instances, by the sudden shutting off or letting on of water at the wheels of the electric street railway company, whose power-house adjoins the testing flume. At or near the quarter hours, all the cars of the system were stopped for a half minute or so at certain transfer stations. These sudden and extreme changes in the load on the wheels at the central power station of course made corresponding fluctuations in the amount of water drawn by the wheels from the canal, and this, in turn, slightly affected the level of the water in the canal near the entrance to the flume. There were seven experiments altogether from which one or two or three readings of H have been rejected. In five of these, the rejected readings occurred at or very near the quarter hour. In five cases, to have retained the full set of readings would have given a greater extreme variation in H than that in Experiment No. 20. For the trapezoidal weir, in experiment 23, the extreme variation would have been 0.0450 instead of 0.0060; in experiment 39, 0.0210 instead of 0.0170. For the rectangular weir, in experiment 10, the extreme variation would have been 0.0240 instead of 0.0030; in experiment 23, 0.0350 instead of 0.0060; and in experiment 39, 0.0215 instead of 0.0155.

In a few other experiments, although the extreme variation in H was above the average, the erratic readings could not be discarded without breaking the continuity of the set. These variations in H for the trapezoidal weir are given in column 14 of Table No. 2, and for the

rectangular weir, in column 5. The largest variation given by column 5 is 0.019 ft. in experiment 20. In the majority of cases, the variation does not exceed 0.008 ft. In column 14, the greatest variation of H is shown to be 0.02 ft.; also in experiment 20, while a large majority do not exceed 0.006 ft. These results are well within the limits of the experiments made by Mr. Francis at the lower locks, in Lowell, Mass., in 1852, his greatest variation in head during an experiment being 0.0315 ft. Of course when a value of H for the trapezoidal weir was rejected, the corresponding valve of H for the rectangular weir was also rejected.

To illustrate the above remarks, a few pages from the note book are reproduced. The time given is that recorded by the observer's watches; it may have varied slightly from that of the street railway people.

Experiment 9.—April 13th, 1893. $l = 4$ ft. Head on trapezoidal weir:

7.20 P.M.,	0.9605 ft.		
7.21 "	0.9575 "		
7.22 "	0.9580 "	Extreme variation in 11 readings,	0.008 ft.
7.23 "	0.9600 "	Arithmetical mean value of H....	0.9603 "
7.24 "	0.9610 "	Mean H by Francis formula.....	0.9602 "*
7.25 "	0.9615 "		
7.26 "	0.9605 "		
7.27 "	0.9605 "		
7.28 "	0.9635 "		
7.29 "	0.9655 "		
7.30 "	0.9650 "		

Experiment 11.—April 13th, 1893. $l = 4$ ft. Head on trapezoidal weir:

8.19 P.M.	0.4510 ft.		
8.20 "	0.4535 "		
8.21 "	0.4500 "	Extreme variation in 11 readings,	0.0110 ft.
8.22 "	0.4515 "	Extreme variation in first 8 readings.....	0.0035 ft.
8.23 "	0.4515 "	Arithmetical mean value of H....	0.4515 "
8.24 "	0.4510 "		
8.25 "	0.4500 "		
8.26 "	0.4535 "		
8.27 "	0.4435 " ? †		
8.28 "	0.4425 " ?		
8.29 "	0.4425 " ?		

* See Page 26.
† Readings marked ? were omitted in reducing the data of the experiment.

Experiment 18.—April 14th, 1893. $l = 4.982$ ft. Head on trapezoidal weir:

11.53 A.M.	0.2385 ft.	
11.54 "	0.2390 "	
11.55 "	0.2395 "	Extreme variation in 11 readings, 0.0060 ft.
11.56 "	0.2410 "	Arithmetical mean value of H.... 0.2390 "
11.57 "	0.2405 "	Mean H by Francis formula..... 0.2391 "
11.58 "	0.2410 "	
11.59 "	0.2405 "	
12.00 M.	0.2390 "	
12.01 P.M.	0.2380 "	
12.02 "	0.2365 "	
12.03 "	0.2350 "	

Experiment 20.—April 14th, 1893. $l = 4.982$ ft. Head on trapezoidal weir:

2.35 P.M.	0.6880 ft.	
2.36 "	0.6885 "	
2.37 "	0.6735 "	Extreme variation in 16 readings, 0.0200 ft.
2.38 "	0.6795 "	Arithmetical mean value of H.... 0.6817 "
2.39 "	0.6835 "	Mean H by Francis formula.... 0.6817 "
2.40 "	0.6935 "	
2.41 "	0.6835 "	
2.42 "	0.6735 "	
2.43 "	0.6820 "	
2.44 "	0.6770 "	
2.45 "	0.6930 "	
2.46 "	0.6835 "	
2.47 "	0.6750 "	
2.48 "	0.6820 "	
2.49 "	0.6765 "	
2.50 "	0.6740 "	

Experiment 22.—April 14th, 1893. $l = 4.982$ ft. Head on trapezoidal weir:

4.09 P.M.	1.1415 ft.	
4.10 "	1.1415 "	
4.11 "	1.1415 "	Extreme variation in 11 readings, 0.0035 ft.
4.12 "	1.1435 "	Arithmetical mean value of H.... 1.1423 ft.
4.13 "	1.1430 "	

4.14 P.M. 1.1420 ft.
4.15 " 1.1415 "
4.16 " 1.1445 "
4.17 " 1.1420 "
4.18 " 1.1410 "
4.19 " 1.1430 "

Experiment 23.—April 14th, 1893. $l = 4.982$ ft. Head on trapezoidal weir:

4.34 P.M. 1.3995 ft.
4.35 " 1.3995 "
4.36 " 1.4000 " Extreme variation in 11 readings, 0.0450 ft.
4.37 " 1.4030 " Extreme variation in first 9 readings..... 0.0060 ft.
4.38 " 1.4035 " Arithmetical mean value of H..... 1.4021 "
4.39 " 1.4015 " Mean H by Francis formula ..... 1.4021 "
4.40 " 1.4055 "
4.41 " 1.4035 "
4.42 " 1.4025 "
4.43 " ..... ?
4.44 " ..... ?

The notes of experiments 11 and 23 are reproduced as examples of cases in which readings of H were rejected. Number 20 is given because in this experiment the greatest variation in H occurred, and because it represents a few cases to which this method of selection could not be applied for the reason that the head fluctuated continually throughout the course of the experiment. Numbers 9, 18 and 22 represent the majority of the experiments, in which the variations were slight. Number 22 is noteworthy for showing so small a variation with so great a depth on the weir.

Each hook-gauge had an adjustable vernier, and, consequently, could be set to read exactly 0.000 when the point of the hook was at the level of the sill of the weir with which the gauge was connected. An 18-in. engineer's V level and a light rod were used in comparing the heights of the sills with the gauges. Several such comparisons were carefully made during the course of the experiments.

The sill lengths were measured with standard 1, 4, 6 and 8-ft. wooden rods made by Darling, Browne & Sharpe, of Providence, R. I.,

and graduated to hundredths of a foot. These rods were tested by Prof. W. A. Rogers, of Cambridge, and found to be very accurate. In order to insure accuracy in the slope of the ends of the trapezoidal weir, a template of hard wood was carefully made, having sides about 2 ft. long, which could be applied to the angles of the weir. By means of the slots and screws mentioned above, the iron plates forming the ends of the weir could be adjusted so as to fit the template to a nicety.

At the close of the 32d experiment, it was noticed that the middle of the temporary dam for the trapezoidal weir had bulged a little. Measurement showed that the center of the sill (set at $l = 7.952$ ft.) was about $\frac{3}{8}$ in. out of line. This deflection proved to be too small to sensibly affect the measurement of l.

The least distance from the end of the sill to the nearer side of the canal of approach L occurred in series VI when $l = 8.943$ ft., and was about 5.5 ft. Since the greatest head in this series was 0.9478 ft., the condition that L must be at least $2\,H$ was abundantly fulfilled. G for the rectangular weir was 5.8 ft., and the greatest head on it was 1.4056 ft. in experiment 32. G for the trapezoidal weir was 7.8 ft., and the greatest head on it was 1.4021 ft. in experiment 23. Hence the requirement that G must be at least $3\,H$ was fully satisfied.

As the temporary dam was made quite tight, there is no correction for leakage to be made in the discharge over the trapezoidal weir. The leakage from the lower basin was determined by shutting the admission gates completely and then taking three or four readings of the hook-gauge, the first just when the water had entirely ceased to flow over the sill of the rectangular weir, the second about five or six minutes later, and the third at the end of 10 or 12 minutes. It was possible to take these small readings below the level of the sill, because the stem of the hook-gauge was graduated for a short distance above the zero point. From these observations the subsidence of the water in a given time was obtained, and knowing the net area of the horizontal cross-section of the basin, the amount discharged in the given time was easily computed. The average was found to be 2.274 cu. ft. per minute, or about 0.038 cu. ft. per second. But this cannot be taken as the rate of leakage during an experiment. Regarding the crevices through which the water escaped as submerged orifices, the discharge through them can be considered as varying nearly in proportion to the square roots of the effective heads upon the orifices. *i. e.*, in proportion to the square

roots of the differences between the water levels in the lower basin and the second level canal into which the weir discharged. The crest of the rectangular weir was about 0.8 ft. above the surface of the water in the second level canal, and so the measurements which gave the above rate of discharge, 2.274 cu. ft. per minute, were made when the effective head on the orifices was approximately 0.8 ft. Hence, to obtain the correction for leakage (M) for any experiment the following formula has been used:

$$M = \frac{2.274\, t\, (h + 0.8)^{\frac{1}{2}}}{\sqrt{0.8}}$$

t being the time in minutes.

The numerical results of 32 experiments are embodied in the table on the folded inset sheet. All quantities are expressed in English units. Some of the columns call for no remarks besides the statements given in the nomenclature; but others need a word of explanation.

Columns 2 and 11, H, give the mean observed heads on the weirs during the experiment. In those cases in which the extreme variation of the head did not exceed 0.005 ft., the arithmetical mean of the hook-gauge readings was taken as the value of H for that experiment. In other cases, the mean head was determined by the use of the formula given by Mr. J. B. Francis, on page 112, Article 150, "Lowell Hydraulic Experiments." It is deduced as follows:

It is very nearly accurate to say that—

$$q = \frac{t'}{2} C l H_1^{\frac{3}{2}} + \frac{t' + t''}{2} C l H_2^{\frac{3}{2}} + \frac{t'' + t'''}{2} C l H_3^{\frac{3}{2}} + \ldots + \frac{t^n}{2} C l H_n^{\frac{3}{2}}$$

$$= C l \left(\frac{t'}{2} H_1^{\frac{3}{2}} + \frac{t' + t''}{2} H_2^{\frac{3}{2}} + \frac{t'' + t'''}{2} H_3^{\frac{3}{2}} + \ldots + \frac{t^n}{2} H_n^{\frac{3}{2}} \right)$$

also $q = T\, C\, l\, H^{\frac{3}{2}}$, approximately. Whence—

$$H = \left(\frac{\frac{t'}{2} H_1^{\frac{3}{2}} + \frac{t' + t''}{2} H_2^{\frac{3}{2}} + \frac{t'' + t'''}{2} H_3^{\frac{3}{2}} + \ldots + \frac{t^n}{2} H_n^{\frac{3}{2}}}{T} \right)^{\frac{2}{3}}$$

in which H_1, H_2, . . . H_n are the observed heads, the arithmetical means being taken of readings varying by not more than 0.002 ft. t', t', t''' . . . t^n are the corresponding intervals of time.

$$T = t' + t'' + t''' + \ldots + t^n.$$

FRANCIS WEIR.—$q = t\,\frac{1}{3}\,(l - 0.2\,h)\,h^{\frac{3}{2}}$

SERIES AND No.	1	2	3	4	5	6	7	8	9	10	11
	t	H	h_a	h	*e. v. h.*	l	q	M	q'	Q	H
I— 8	600	1.1731[3]	0.0002	1.1734	0.0055	4.000	9571.933	35.722	9607.655	16.013	1.1483
9	600	0.9790[3]	0.0001	0.9792	0.0055	4.000	7372.256	33.904	7406.160	12.344	0.9612[3]
10	420	0.8027	0.0001	0.8028	0.0030	4.000	3866.357	22.531	3888.888	9.259	0.7862
11	420	0.4584	.....	0.4584	0.0020	4.000	1698.180	19.964	1718.144	4.091	0.4515
12	600	0.3538[3]	.....	0.3538	0.0055	4.000	1653.756	27.310	1681.066	2.802	0.3475
13	600	0.2653	.....	0.2653	0.0045	4.000	1078.676	25.241	1104.917	1.841	0.2600
II—14	600	0.5114[3]	.....	0.5114	0.0080	4.000	2850.778	29.123	2879.901	4.800	0.3780[3]
15	600	0.2489	.....	0.2489	0.0025	4.000	981.041	26.038	1007.079	1.678	0.1937
16	600	0.7094[3]	.....	0.7094	0.0075	4.000	4610.415	31.235	4641.650	7.736	0.5396
17	600	1.0218[3]	0.0002	1.0221	0.0070	4.000	7844.236	34.319	7878.555	13.131	0.7723
III—18	600	0.2730[3]	.....	0.2730	0 0075	4.000	1125.552	26.336	1151.888	1 920	0.2391[3]
19	600	0.5395[3]	.....	0.5395	0.0105	4.000	3084.780	29.425	3114.205	5.190	0.4648[3]
20	900	0.7932[4]	.....	0.7932	0.0190	4.000	8141.132	48.136	8189.268	9.099	0.6817[4]
21	600	0.9983[3]	0.0001	0.9985	0.0085	4.000	7583.509	34.096	7617.605	12.696	0.8490
22	600	1.0056	0.0003	1.0060	0.0045	6.000	11702.135	34.167	11736.302	19 561	1.1423
23	480	1.2340[3]	0.0006	1.2348	0.0060	6.000	12630.215	29.013	12659.228	26.373	1.4021[3]
IV—24	420	0.3811	.....	0.3811	0.0030	6.000	1951.140	19.341	1970.481	4.692	0.3493
25	600	0.7029	.....	0.7029	0.0020	6.000	6905.952	31.168	6937.120	11.562	0.6392
26	600	0.9236	0.0003	0.9240	0.0030	6.000	10329.714	33.382	10363.096	17.272	0.8379
27	600	1.1919	0.0005	1.1926	0.0035	6.000	15007.474	35.889	15043.363	25.072	1.0714
28	600	0.2554[3]	.....	0.2554	0.0085	6.000	1535.675	26.119	1561.794	2.603	0.2363[3]
V—29	600	0.3679[3]	.....	0.3679	0.0070	6.000	2644.945	27.476	2672.421	4.454	0.3089[3]
30	600	0.6503[3]	.....	0.6503	0.0060	6.000	6156.465	30.618	6187.083	10.312	0.5425
31	600	1.0868	0.0004	1.0874	0.0045	6.000	13113.879	34.923	13148.802	21.915	0.8924
32	600	1.4059[3]	0.0008	1.4070	0.0065	6.000	19088.022	37.766	19125.788	31.876	1.1518
VI—33	480	0.6555[5]	.....	0.6555	0.0180	6.000	4983.529	24.535	5008.064	10.434	0.4971[4]
34	600	0.3863	.....	0.3863	0.0050	6.000	2844.013	27.691	2871.704	4.786	0.2940
35	600	0.9061	0.0003	0.9065	0.0020	6.000	10044.051	33.212	10077.263	16.795	0.6844
36	600	1.2532	0.0006	1.2540	0.0045	6.000	16146.691	36.437	16183.128	26.972	0.9472
VII—37	180	0.7044[3]	.....	0.7044	0.0100	3.000	1014.166	9.355	1023.521	5.686	0.7030
38	300	0.9539[4]	0.0001	0.9540	0.0120	3.000	2617.609	16.836	2634.445	8.781	0.9436[4]
39	240	0.3168[5]	.....	0.3168	0.0155	3.000	418.917	10.752	429.667	1.790	0.3275[5]

TABLE No. 2.

CIPPOLETTI WEIR.—$C = \frac{Q}{l\, h^{\frac{3}{2}}}$ SMITH FORMULA.—

11	12	13	14	15	16	17	18	SERIES AND No.	19	20	2
H	h_a	h	$c.v.h.$	l	C	c'	Per Cent. of Error.		c	q_1	q
1.1483	0.0001	1.1485	0.0045	4.000	3.253	.608	3.39	I— 8	.595	9705.244	9740
0.9612[3]	0.0001	0.9613	0.0080	4.000	3.274	.612	2.76	9	.599	7448.270	7482
0.7862	.....	0.7862	0.0050	4.000	3.321	.621	1.37	10	.602	3889.786	3912
0.4515	.....	0.4515	0.0035	4.000	3.371	.630	+ 0.12	11	.612	1706.231	1726
0.3475	.....	0.3475	0.0050	4.000	3.420	.639	+ 1.57	12	.618	1668.958	1696
0.2600	.....	0.2600	0.0050	4.000	3.472	.649	+ 3.12	13	.624	1094.239	1120
0.3780[3]	.....	0.3780	0.0055	5.990	3.448	.645	+ 2.41	II—14	.610	2862.703	2891
0.1937	.....	0.1937	0.0025	5.980	3.292	.616	1.96	15	.625	995.952	1021
0.5396	.....	0.5396	0.0035	5.980	3.264	.610	3.06	16	.604	4631.213	4662
0.7723	0.0001	0.7724	0.0020	5.980	3.238	.605	3.92	17	.598	7929.818	7964
0.2391[3]	.....	0.2391	0.0060	4.982	3.296	.617	2.11	III—18	.623	1140.393	1166
0.4648[3]	.....	0.4648	0.0135	4.982	3.287	.615	2.38	19	.609	3096.886	3126
0.6817[5]	.....	0.6817	0.0200	4.982	3.245	.607	3.62	20	.602	8186.226	8234
0.8490	0.0001	0.8491	0.0025	4.982	3.257	.609	3.27	21	.598	7656.737	7696
1.1423	0.0002	1.1426	0.0035	4.982	3.215	.601	4.51	22	.603	11711.865	11746
1.4021[3]	0.0003	1.4026	0.0060	4.982	3.187	.596	5.35	23	.599	12656.822	12683
0.3493	.....	0.3493	0.0045	6.963	3.264	.611	3.06	IV—24	.618	1959.104	1978
0.6392	.....	0.6392	0.0015	6.963	3.249	.608	3.50	25	.608	6896.952	6928
0.8379	0.0002	0.8381	0.0020	6.963	3.233	.605	3.98	26	.604	10326 595	10355
1.0714	0.0003	1.0719	0.0050	6.963	3.245	.607	3.62	27	.599	15016.886	15052
0.2363[3]	.....	0.2363	0.0090	6 963	3.255	.609	3.33	28	.627	1557.799	1582
0.3089[3]	.....	0.3089	0.0060	7.952	3.263	.610	3.09	V—29	.618	2654.573	2682
0.5425	.....	0.5425	0.0045	7.952	3.245	.607	3.62	30	.609	6147.521	6178
0.8924	0.0003	0.8928	0.0045	7.952	3.267	.611	2.97	31	.601	13118.121	13153
1.1518	0.0005	1.1525	0.0050	7 952	3.243	.606	3.68	32	.596	19146.982	19184
0.4971[4]	.....	0.4971	0.0090	8.943	3.329	.623	1.13	VI—33	.609	4977.126	5001
0.2940	.....	0.2940	0.0040	8.943	3.357	.628	0.30	34	.617	2851.546	2879
0.6844	0.0002	0.6846	0.0025	8.943	3.315	.620	1.54	35	.605	10051.227	10084
0.9472	0.0004	0.9478	0.0035	8.943	3.269	.611	2.91	36	.598	16164.424	16200
0.7030	.....	0.7030	0.0030	2.970	3.248	.607	3.53	VII—37	.603	1029.319	1033
0.9436[4]	.....	0.9436	0.0150	2.970	3.226	.603	4.19	38	.596	2672.519	2689
0.3275[5]	.....	0.3275	0.0170	2.970	3.216	.601	4.48	39	.618	424.236	434

ORMULA.—$q_1 = t\, c\, \frac{2}{3}\sqrt{2g}\; l\, h^{\frac{3}{2}}$

	21	22	23	24	25	26	27
	$q_1{}^1$	Q'	C'	$c_1{}^1$	Per Cent. of Error.	Temp. Fahr.	Remarks.
244	9740.966	16.235	3.298	.617	2.06	Air, 46°	
270	7482.174	12.470	3.308	.619	1.75	Water, 39.5°	
786	3912.317	9.315	3.342	.625	0.74		
231	1726.195	4.110	3.387	.633	+ 0.59		
958	1696.268	2.827	3.450	.645	+ 2.46		
239	1120.480	1.867	3.521	.658	+ 4.57		
703	2891.826	4.820	3.463	.648	+ 2.85		
952	1021.990	1.703	3.341	.625	0.77	Air, 45°	
213	4662.448	7.771	3.278	.613	2.64	Water, 39.5°	
818	7964.137	13.274	3.270	.612	2.88		
393	1166.729	1.945	3.339	.624	0.83		
886	3126.311	5.211	3.301	.617	1.96		
226	8234.362	9.149	3.263	.610	3.09		
737	7690.833	12.818	3.288	.615	2.35		
665	11746.032	19.577	3.217	.602	4.46	.....	Water at rectangular weir not very smooth.
922	12685.835	26.428	3.194	.597	5.14		
104	1978.445	4.712	3.278	.613	2.64		
952	6928.120	11.547	3.245	.607	3.62		
595	10359.977	17.267	3.232	.605	4.01		
886	15052.775	25.088	3.247	.607	3.56	.....	do.
799	1583.918	2.640	3.301	.617	1.96		
573	2682.049	4.470	3 274	.612	2.76		
521	6178.139	10.297	3.241	.606	3.74		
121	13153.044	21.922	3.268	.611	2.94	Air, 45°	
982	19184.748	31.975	3.253	.608	3.39	Water, 38°	do.
126	5001.661	10.420	3.325	.622	1.25		
546	2879.237	4.799	3.366	.630	0.03		
227	10084.439	16.807	3.318	.621	1.46		
424	16200.861	27.001	3.272	.612	2.82	.....	do.
319	1038.674	5.770	3.296	.616	2.11	.....	Fluctuating head.
519	2689.355	8.964	3.293	.616	2.20		
236	434.988	1.812	3.255	.609	3.33		

TABLE No. 1.

Number of Experiments.	Duration. Minute.	Head on Rectangular Weir.		Difference between 3 and 4.	Extreme variation in H.	Head on Trapezoidal Weir.		Difference between 7 and 8.	Extreme Variation in H.
		Arith. Mean.	Formula.			Arith. Mean.	Formula.		
1	2	3	4	5	6	7	8	9	10
$8_{..}$	10	1.1732	1.1731	− 0.0001	0.0055				
$9_{..}$	10	0.9791	0.9790	− 0.0001	0.0055	0.9612	0.9612	.....	0.0080
$12_{..}$	10	0.3539	0.3532	− 0.0001	0.0055				
$14_{..}$	10	0.5113	0.5114	+ 0.0001	0.0080	0.3780	0.3780	.....	0.0055
$16_{..}$	10	0.7094	0.7094	.....	0.0075				
$17_{..}$	10	1.0216	1.0218	+ 0.0002	0.0070				
$18_{..}$	10	0.2727	0.2730	+ 0.0003	0.0075	0.2390	0.2391	+ 0.0001	0.0060
$19_{..}$	10	0.5397	0.5395	− 0.0002	0.0105	0.4650	0.4648	− 0.0002	0.0135
$20_{..}$	15	0.7928	0.7932	+ 0.0004	0.0190	0.6817	0.6817	.....	0.0200
$21_{..}$	10	0.9982	0.9983	+ 0.0001	0.0085				
$23_{..}$	8	1.2341	1.2340	− 0.0001	0.0060^{3}	1.4021	1.4021	.....	0.0060
$28_{..}$	10	0.2554	0.2554	.....	0.0085	0.2363	0.2363	.....	0.0090
$29_{..}$	10	0.3677	0.3679	+ 0.0002	0.0070	0.3087	0.3089	+ 0.0002	0.0060
$30_{..}$	10	0.6505	0.6503	− 0.0002	0.0060				
$32_{..}$	10	1.4056	1.4059	+ 0.0003	0.0065				
$33_{..}$	8	0.6549	0.6555	+ 0.0006	0.0180	0.4971	0.4971	.....	0.0090
$37_{..}$	3	0.7039	0.7044	+ 0.0005	0.0100				
$38_{..}$	5	0.9542	0.9539	− 0.0003	0.0120	0.9439	0.9436	− 0.0003	0.0150
$39_{..}$	4	0.3169	0.3168	− 0.0001	0.0155	0.3277	0.3275	− 0.0002	0.0170

The small figures to the right and above the values of H in these columns show the number of combinations of readings, used in finding the mean, *i. e.*, they give the values of the subscript n in the above formula.

The above Table No. 1 compares the mean values of H as obtained by the use of the formula with the arithmetical means. The results in columns 5 and 9 would seem to show that the error arising from taking an arithmetical mean of the readings of the hook-gauge instead of deducing the mean value of H by the more correct method depends not so much upon the range of the variations of the readings, as upon the relation of each reading to the arithmetical mean—the grouping, so to speak, of the readings about the arithmetical mean as a center of gravity. In any case, the difference is too small to be worth taking account of in the ordinary use of the weir, and seems equally liable to be positive or negative. Hence, in a series of measurements, these errors would tend to balance one another. It is concluded from this, therefore,

that in the great majority of cases, it is safe to take the arithmetical mean of the hook-gauge readings as the value of the head.

Columns 3 and 12, h_a, give the values of the heads corresponding to the velocities of approach. These values were obtained by use of the formula :

$$h_a = 0.01555 \left(\frac{Q_1}{A}\right)^2,$$

in which Q_1 is the approximate value of the discharge given by the formula :

$$Q_1 = \frac{10}{3} l H^{\frac{3}{2}}.$$

Columns 4 and 13, h, give the values of the effective heads on the weirs. In correcting for velocity of approach, Mr. Hamilton Smith, Jr.'s, method has been followed, employing his formula for weirs with complete contractions :

$$h = H + 1.4\, h_a.$$

Columns 5 and 14 give the extreme variation in H during an experiment, *i. e.*, the difference between the lowest and the highest reading of the hook-gauge.

Columns 7, 9, 10, 16, 17 and 18 were computed from the results obtained by substituting in the formula :

$$q = t \frac{10}{3} (l - 0.2\, h)\, h^{\frac{3}{2}},$$

in which 0.623 is taken as the value of the coefficient of contraction.

Columns 20, 21, 22, 23, 24 and 25 were computed from the results obtained by the use of the formula :

$$q_1 = t\, c\, \tfrac{2}{3} \sqrt{2g}\, l\, h = 5.347\, t\, c\, l\, h^{\frac{3}{2}}.$$

Column 19 gives the values of c used in the above formula. These values were obtained by interpolating in Table No. 48, page 132, Hamilton Smith, Jr.'s, "Hydraulics."

Columns 18 and 25 show the percentage of variation of the coefficient for the trapezoidal weir, as deduced from the data of the experiments, from $3.36\frac{2}{3}$, the coefficient deduced by Cippoletti's mathematical research.

$$\text{Per cent. of error} = 3.3\ \tfrac{2}{3} \sim C \div .03367.$$

Conclusions.

The experiments would have been much more satisfactory if the discharge from the trapezoidal weir could have been measured by direct cubic measurements. Nevertheless, the writers believe that they can fairly say that their work was done with sufficient care, and the apparatus used was accurate enough to give results of some practical value.

The discharge of the rectangular weir has been computed in two ways; first, by using the Francis formula—

$$q = t\,\tfrac{1.0}{3}\,(l - 0.2\,h)\,h^{\frac{3}{2}},$$

in which the coefficient of contraction has the constant value 0.623, the value assumed by Cippoletti in deducing his coefficient; second, by employing the formula—

$$q = t\,c\,\tfrac{2}{3}\,\sqrt{2g}\,l\,h^{\frac{3}{2}},$$

which for this locality becomes—

$$q = 5.347\,t\,c\,l\,h^{\frac{3}{2}},$$

the values of c being taken from the table compiled by Mr. Hamilton Smith, Jr. The values of C computed from either set of figures, with a few exceptions in each case, indicated by plus signs in columns 18 and 25, fall below $3.36\frac{2}{3}$.

Why these four experiments, Nos. 11 to 14 inclusive, should give values of C greater than the theoretical value, while all the others give results which fall below the theory, the writers are at a loss to explain. These experiments were made with same care as the others, and no peculiar conditions were designedly introduced, nor were there any accidental causes of error in these, as far as observed, different from those in the others. These four experiments were made at the close of the evening's work on April 13th, but the fact of their having been made in the evening does not of itself seem a sufficient reason for the peculiarity of their results, for Nos. 9 and 10 and Nos. 25 to 30, inclusive, were also made in the evening, and their results exhibit no such departure from the majority.

The results of the Smith formula vary less from Cippoletti's assumed value of C, but differ a little more from their own average than do those given by the Francis formula. In studying the percentages of error in columns 18 and 25, to discover if there were any law gov-

erning their variation, it was found that (with five or six exceptions) in each series, as the heads increased, the per cent. of negative variation of C, from 3.36$\frac{2}{3}$ also increased. This seems to indicate that the increase of the area of the vein due to the inclination of the sides of the weir is not quite sufficient to compensate for the effects of the end contractions; for, if the discharge through the added triangles were just equal to the diminution of the total discharge due to the effects of end contraction, and if the rectangular weir, by using the Francis formula, would give the discharge with an error not greater than 1%, we should naturally expect that the variations in the error would not follow the changes in the head, but that the coefficient would be as likely to show a positive as a negative error (due to inaccuracies in experimentation) and would depart in either direction but 1 or 2% from the value theoretically deduced from the Francis coefficient. However, the writers feel somewhat reluctant about drawing any such conclusion from the few experiments which they had opportunity to make, and the more so because they were unable to measure the discharge directly, but were obliged to determine it by the aid of the rectangular weir.

It may be, however, that the explanation of this connection between the error and the head is to be sought in the arrangement of the apparatus. That is to say, the water, as it approached the rectangular weir, may have had a greater velocity due to its fall from the trapezoidal weir than was suspected, and it may be that there should be a greater allowance made in the discharge on this account than the usual correction for velocity of approach. On this point, all that can be said with assurance from actual observation is, that the surface of the water was smooth, and that chips or other light surface floats showed only a very slight velocity, excepting in the cases where it is noted to the contrary. Of course, the greater the head, the larger would be the quantity of water falling, and, consequently, the greater the difficulty in overcoming the velocity due to its fall from the Cippoletti weir. Hence, possibly, the increasing error with the increase of head.

Results given by the formulas, making a reasonable allowance for inaccuracies of observation in careful work, are generally considered to be liable to an error of about 1%, *i. e.*, the discharge may as truthfully be said to be either $q + 0.01q$ or $q - 0.01q$ as to be called q. Now, in these experiments, since the water was given an initial velocity by its fall from the trapezoidal weir, and since it is probable that this

velocity was not entirely overcome before the water reached the rectangular weir (although the surface was made quite smooth by the devices used), it seems fair to assume that the balance of error was in favor of increasing the discharge. The average value of C in column 16 is 3.283. Making the correction in q by adding $0.01q$, the value of C becomes 3.316, which varies from $3.36\frac{2}{3}$ by 1.51 per cent. But a few of the experiments should not have equal weight with the others. In Nos. 22, 23, 27, 32 and 36, the surface of the water was noticeably agitated as it approached the rectangular weir; and in experiments 37, 38 and 39 the head fluctuated rapidly, because these tests were made at noon time on Saturday, when many of the large mills were shutting down. Omitting these, the average value of C in column 16 becomes 3.301; and, making the correction in q, as above, C now becomes 3.334, which differs from $3.36\frac{2}{3}$ by 0.98 per cent.

Considering the results given by Smith's formula, the average value of C' is found in column 23 to be 3.304. Correcting q_1 in the same way as q above, C' becomes 3.337, which varies from $3.36\frac{2}{3}$ by 0.030 or 0.89 per cent. Omitting numbers 22, 23, 27, 32, 36, 37, 38 and 39, as before, the average value of C' is found to be 3.321; and increasing q_1 for the remaining experiments by 1%, as before, C' becomes 3.354, which differs from $3.36\frac{2}{3}$ by 0.013, or 0.39 per cent.

Therefore, the writers think it fair to conclude from these results that Cippoletti's formula, $Q = C\,l\,h^{\frac{3}{2}}$, when applied to a properly constructed trapezoidal weir, will give the discharge with an error, due to the combined inaccuracies, not greater than one per cent.

Cippoletti's object was to determine a form of weir and a formula which should measure the discharge with an error arising from any one disturbing cause not greater than $\frac{1}{2}$ of one per cent. In order to attain to this standard, the weir must satisfy the following requirements, in addition to those usual for all weirs:

"There must be complete contraction at each end and on the bottom.

"The velocity of approach must be small, not exceeding 0.5 ft. per second for weirs 1 m. (39.37 ins.) long, with a head 1 ft., or 0.66 ft. for weirs 2 m. long, with a head of 2 ft. The cross-section of the canal of approach should be at least seven times that of the vein of water in the plane of the weir.

"The inaccuracy in the measurement of the head should not exceed one-third of one per cent.

"The weir should not vary more than 4° from being perpendicular to the canal of approach.

"The sill must be horizontal." *

The principal advantage claimed for the trapezoidal weir is that the computations are much simpler than for any other form of weir. Anybody who can read a simple gauge and can multiply can use this weir after it has been properly installed, for if a table be compiled giving the discharge over a 1-ft. sill, with various heads, the discharge for any sill length can be obtained by multiplying the number in the table under the given head by the length of the given sill. This obtains because of the automatic elimination of the effect of end contraction, making the discharge for any given head vary directly as the sill length, which the writers have found to be nearly true experimentally, as can be readily deduced from the table.

There are no two experiments in the set between which a direct comparison of the effects of a variation in l alone can be made, for it was not practicable to get the head on the weir exactly the same in two experiments. However, there are two or three cases in which the variation in h is small. According to the formula, $\frac{Q_1}{Q_2} = \frac{l_1 h_1^{\frac{3}{2}}}{l_2 h_2^{\frac{3}{2}}}$.

Comparing experiments Nos. 12 and 24, we find a difference of only 0.0018 ft. in the head. Substituting in the above expression, we have $2.827 \div 4.712 = 0.60$ and $(4.000 \times 0.3475^{\frac{3}{2}}) \div (6.963 \times 0.3493^{\frac{3}{2}}) = 0.57$. But from column 25, we see that the results of No. 12 have a positive variation from the theoretical coefficient of 2.46%, while the results of No. 24 have a negative variation of 2.64 per cent. Comparing in a similar manner experiments Nos. 18 and 28, where the difference in head is 0.0028 ft., we have $1.945 \div 2.640 = 0.74$, and $(4.982 \times 0.2391^{\frac{3}{2}}) \div (6.963 \times 0.2363^{\frac{3}{2}}) = 0.73$. Here, the respective errors in column 25 are 0.83% and 1.96%, both negative.

According to the formula, Q should vary, also, directly as $h^{\frac{3}{2}}$. The experimental results fulfill this requirement very nearly. Comparing Nos. 15 and 17, we have $1.703 \div 13.274 = 0.128$, and $0.1937^{\frac{3}{2}} \div 0.7724^{\frac{3}{2}} = 0.126$. Likewise in Nos. 18 and 21, we have $1.945 \div 12.818 = 0.152$, and $0.2391^{\frac{3}{2}} \div 0.8491^{\frac{3}{2}} = 0.149$. A number of other similar comparisons show equally good or better results.

The trapezoidal weir can be used as a divisor, therefore, and is

* From "Canale Villoresi," etc.

especially adapted to use on irrigation canals. For about 10 years it has been employed in Italy, and has given general satisfaction. One of the chief objections to all measuring devices used on irrigating systems has been their unfairness in that their inaccuracies favored the users of the larger quantities of water. Cippoletti has overcome this, it is claimed. The trapezoidal weir, if it favors any one, probably favors slightly the consumers of the smaller quantities of water.

The authors regret that the experiments have so limited a range. However, they respectfully submit the above figures to the engineering profession, trusting that the fruits of these labors may not be entirely without practical value. Some of the deductions may be erroneous, but they have tried to record the results accurately and honestly. Others may make such interpretations for themselves as their experience and judgment may direct.

The authors wish to acknowledge their indebtedness to the Holyoke Water Power Company for the use of its testing flume and the accompanying conveniences; to Mr. A. Frank Sickman, hydraulic engineer of the above company, for valuable suggestions and personal assistance; to Mr. J. M. Goodell, Assoc. Am. Soc. C. E., assistant editor of the *Engineering Record*, and to Prof. L. G. Carpenter, of the State Agricultural College, Fort Collins, Colorado, for information and literature.

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TESTS OF CONDENSATION IN CAST-IRON RADIATORS.

By WILLIAM J. BALDWIN, M. Am. Soc. C. E.

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The writer had occasion recently, in connection with his professional work, to make some comparisons as to the relative efficiencies of several of the regular makes of cast-iron radiators now on the market, and ones that are considered good types of direct cast-iron radiators. The results of the experiments hereinafter given were obtained from four of these radiators that were selected as a standard of comparison for a new radiator about to be put on the market. The results of these experiments are given to this Society, as they form valuable data by which an engineer can approximate the amount of condensation likely to take place in the heating apparatus of a building, and also show how near the line of condensation agrees in steam pipes with a line of the difference of temperature between air and steam.

The writer is compelled to omit the name and make of these four types, but as the results run so nearly together he presumes it is not necessary to go further than to say that they are the ordinary well-known types of cast-iron sectional radiators that are so much used at

the present day. All radiators were of 48 sq. ft. of surface, according to their commercial rating, excepting that designated as No. 3, which contains 52 sq. ft. and which, when reduced to the value of 48 sq. ft., gives the dotted line shown and designated as *X*—*X* (Plate IV).

The method of comparison used was that known as the condensation test, the only one which is of any value in determining the comparative value of radiators, and consisted of taking steam from a boiler at 90 lbs. pressure and conveying it in a 1-in. pipe to a water separator. This water separator was "trapped" in the usual manner with a Nason trap. From the top of the separator a 1-in. pipe led to a reducing pressure regulating valve and from the pressure regulating valve it led into a header of 2 ins. inside diameter. The connection for each radiator was made of ¼-in. pipe, taken from the upper side of this header through a short nipple, and thence by another short nipple into the radiator, an angle valve being used at the corner. It is probable that the condensation taking place in the two short nipples and in the valve was carried forward into the radiator; but, the quantity being so small, it has not been considered, as it was the same in each case.

The radiators were placed on platforms 2 ft. above the floor and 36 ins. from center to center. Over each radiator was placed a frame covered with muslin. The muslin in all cases was 6 ins. from the sides and ends of the radiators, and the frames were opened top and bottom. The frames had the same perpendicular height as the radiator, and were raised sufficiently (about 6 ins.) to permit an uninterrupted flow of air to the radiator underneath the lower edge of the frame. This method enclosed each radiator in a cotton box, as it were, and interposed two thicknesses of muslin between opposing sides of radiators, so as to cut off almost entirely the effects of radiation from one radiator to another. The tables on which the radiators were set had an inclination of about 1 in. to the drip end, so that the condensation could easily gravitate to the apparatus for collecting the water.

The apparatus for collecting and measuring the water consisted of a ⅜-in. "tail pipe," on the side of which was a short ordinary water gauge glass. Both above and below the water glass in the tail pipe was a stop valve; the upper valve being for the purpose of shutting off the connection should the gauge glass break, but during the experiments it was always open. The lower valve was simply a tail valve, to control the escape of water. The tail valve was supplied with 1 ft.

of very light rubber hose ($\frac{3}{8}$ in.) which terminated in a paper pail. The water was drawn into the paper pail through the tail valve, but was always kept in sight in the glass and made to agree with a thread around the middle of the glass, both at the commencement and the end of all trials.

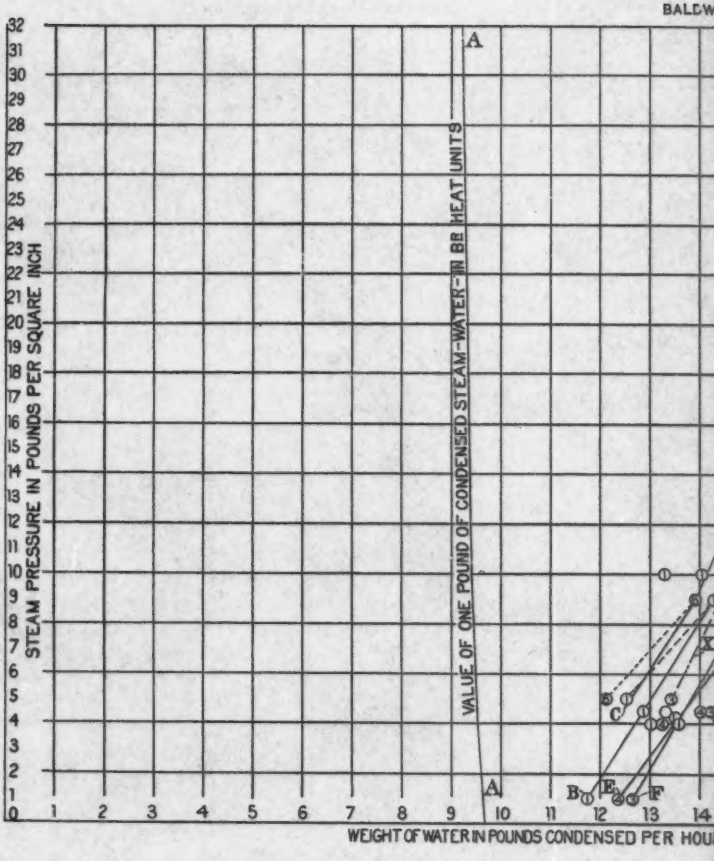
On the header before mentioned was arranged a steam-pressure gauge, and in an oil well in the upper side of the same header was fixed a standard thermometer for the purpose of checking errors in the steam-pressure gauge by comparisons with the temperature of the steam. It will be noted that the trials were generally made at 1, 5, 10, 18 and 30 lbs. pressures, but that some of the circles indicating trials are on other lines, notably in the neighborhood of 5 and 10 lbs. Where the greater number of trials are shown, these differences of pressure are the results of corrections made by the thermometer, the pressure gauge being somewhat inaccurate and the pressures likely to fluctuate $\frac{1}{2}$ lb., or thereabouts; as a pressure-regulating valve is only an approximate instrument for work of this kind. At the lower pressures (1 to 5 lbs.) there is very little loss due to the evaporation of the hot water as it falls into the pails, especially as the end of the hose is kept under water as much as possible. At the higher trials, a small percentage of the hot water, when relieved of its pressure, is converted into steam. This is obviated in a great measure, however, by keeping the end of the hose always under water, which can be done as soon as condensation forms in the bottom of the pail and covers the mouth of the hose.

It is well to remark here that the header before spoken of and in which steam at reduced pressures was admitted to the radiators was also drained and kept dry by an automatic steam trap. The positions of the radiators were also changed from time to time, as it was feared that a radiator in one position might be favored over the others.

At the left of the diagram is shown the steam pressure in pounds per square inch at which various trials were made.

The next line, *A*—*A*, gives the value in British heat-units of each pound weight of steam for the various pressures, and is measured from the left-hand side of the diagram, each of the larger squares having a value of 100 heat-units, the thermal value of a pound weight of steam being less from the higher pressures.

The curved line *B*—*B* shows the results obtained in the radiator designated as No. 1, and they were made under conditions of very


STEAM PRESSURE IN POUNDS PER SQUARE INCH
VALUE OF ONE POUND OF CONDENSED STEAM-WATER IN BR. HEAT UNITS
A
A
B
C
E
F
WEIGHT OF WATER IN POUNDS CONDENSED PER HOU

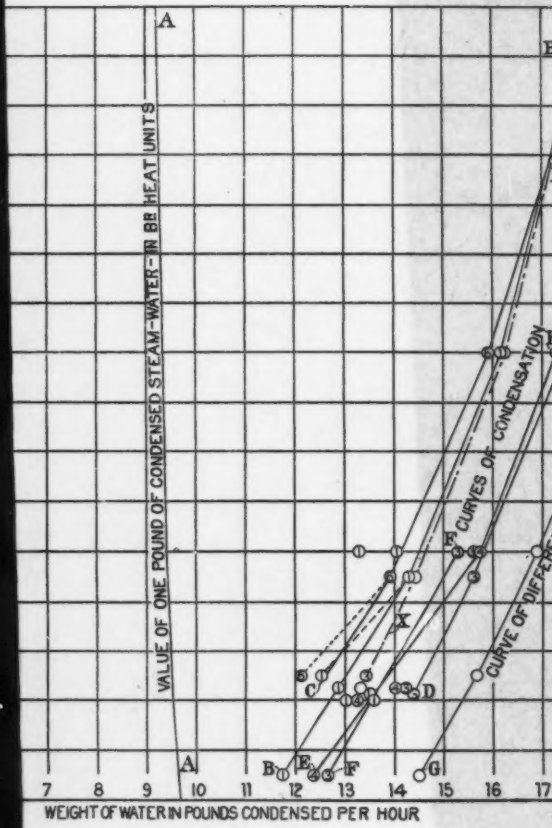
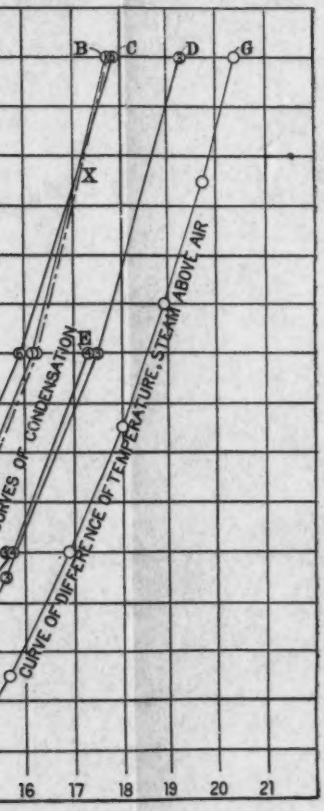

A
VALUE OF ONE POUND OF CONDENSED STEAM-WATER- IN BR HEAT UNITS
CURVES OF CONDENSATION
CURVE OF DIFFE
X
C
D
A
B
E
F
G
7
8
9
10
11
12
13
14
15
16
17
WEIGHT OF WATER IN POUNDS CONDENSED PER HOUR

PLATE IV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 716.
CONDENSATION IN CAST-IRON RADIATORS.



nearly equal temperature, in a room kept constantly between 73 and 74° Fahr.

Line *C—C* shows results obtained for radiator marked No. 6 in the trials, which were made at the same pressures and the same temperatures as the foregoing.

Line *D—D* gives the curve of condensation in the radiator marked No. 3 temperatures and pressures of steam being the same as before.

Line *E—E* shows the results of experiments on radiator No. 4, which at the lower temperatures seems not to do so well. Between the 10-lb. and 18-lb. lines, however, the curve agrees with the remaining curves of condensation.

Line *F—F* shows the other experiments made with radiator No. 3, when the temperature of the room averaged between 77 and 78°. This undoubtedly accounts for the line showing the less condensation on that day. The circles 6, 1 and 3 on the 5-lb. line are also results of the tests made when the temperature of the room was about 78°. Other circles enclosing figures in close proximity to lines, with corresponding figures, show values obtained with the same radiator during other trials and under slightly different conditions of the temperature and humidity. They all harmonize, however, with the curves of their respective radiators and tend to confirm the results.

Line *G—G* is the curve of difference of temperature between the steam and the air, and is drawn for comparison with the curves of condensation as discovered by the trials. The uniformity that exists is remarkable. There is a correction, however, to be made for the higher temperatures in the matter of the curves of condensation. As the temperature of the steam advances, the value of 1 lb. of condensation becomes less, as shown in the line *A—A*, so that curves of efficiency of condensation, based on the actual amount of heat lost from the radiator, and not from the number of pounds of water condensed, would all tend a little to the left as they go upward, bending away from the curve of difference of temperature. It is well known that the condensation does not increase directly as the difference of temperature. These experiments, however, show that it (the difference) is not as great as was surmised, and that for all practical purposes the curve of condensation and the curve of difference of temperature is practically alike for any ranges of temperature and pressures carried in low-pressure steam heating apparatus.

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717.

(Vol. XXXII.—July, 1894.)

NOTES ON WIRE ROPE TRAMWAYS.

By A. C. SAVAGE, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

The use of wire ropes for transportation in rough country or upon steep inclines is by no means a novelty, and the various methods in use are familiar to most of us, at least in a general way.

It is more with a view of calling attention to the methods adopted in surmounting obstacles in the construction and operation of these lines than with the idea of imparting any very novel information that these notes have been made.

It has been the writer's fortune for the past seven years to be connected in a greater or less degree with wire rope tramway building, and for the past three years he has been engaged in active construction of lines in the United States and Mexico for the Trenton Iron Company.

It is well known that two systems of wire rope lines are in general use, the single and double rope systems. The former is the older of the two, and probably the better known, and is also divided into two systems, one in which the buckets or carriers are detached from the

rope at the terminals, and the other, more commonly in use, where the buckets are rigidly fastened to and are carried by the rope around the terminal wheels, being loaded and unloaded in transit, in some instances by hand, in others by automatic devices, which are more or less successful, owing to the character of the material to be conveyed.

It is manifest that where the load is attached directly and only to the hauling rope the matter of divergence from a regular grade line is of less consequence than in the cases where the strains upon two sets of ropes are considered, and hence the expenses of construction are lessened. In cases, therefore, of small outputs, these single rope lines have a signal advantage in first cost. When, however, the production approaches the limit of their capacity, and is of necessity regular, the great wear, frequent repairs and constantly recurring stoppages render them objects of unceasing solicitude to all parties concerned, and it has been too frequently the case that buyer and seller seem to have entered into a combination to do each other and themselves all the injury possible by fixing on a plant which was inadequate to the needs of the user, and, by its failure, an injury to the reputation of a really good machine when properly used.

The double rope lines have these advantages, that with proper designing and construction the limit to their capacity is far in advance of the possibilities of single rope lines; that the wear on their component parts by skillful adjustment may be reduced to a minimum, and the cost of repairs made very small; and that under competent management the most excellent results as to regularity of operation may be attained.

The designing of one of these lines is seldom a simple and easy piece of work. The instances where the "standard terminals" can be employed, and the intermediate supports put in at the ideal distances of from 150 to 200 ft. apart, are few and far between.

In most instances the line must be accommodated to peculiarities of the case, which, while not insurmountable, are, nevertheless, frequently perplexing.

The forms these difficulties assume are generally—

First.—A cramped location for one or both terminals.

Second.—Heavy grades into or out of the terminals.

Third.—Intervening summits on the line.

Fourth.—Intervening hollows or chasms of great width.

The first trouble of cramped location is perhaps the ever-present one, especially at the upper terminal in mine tramways.

The steep side hills most suitable for terminals, and offering the greatest facilities for waste dumps, offer but little foothold for the necessary floor space for a tramway terminal. For width with the standard 8-ft. line 20 ft. will do, though 24 ft. is better, but for length 60 ft. is none too much. Room should be left behind the machinery for switches, on which empty cars may stand when not in use.

But it is when this is combined with the second case, that of heavy grades at the upper terminal, that its worst features are manifest. An example of this is the upper terminal of the "Ground Hog" lines, situated on the rim of Silver Bow Basin, near Juneau, Alaska, and recently completed under the supervision of the writer. The only available spot on the whole mountain side was selected.

The outgoing grade is 60%, and it was impracticable to support the line at the immediate foot of the bluff, as the support must have stood directly in the track of a very heavy annual snow slide. The vertical curve of the trestle in front of the terminal has a radius of 200 ft., and over this the rope is carried in saddles on cross-ties 2 ft. apart.

The difficulties with this arrangement are twofold. First, the great strain on the traction rope and bucket frames arising from the transition from the level grade at the attaching point to the 60% grade at the end of the trestle. An inclined terminal would obviate this, and a good deal of study has been given to this point and many expensive experiments made by the engineers of the Trenton Iron Company without achieving satisfactory results, the trouble lying in the difficulty of attaching the loaded bucket to the traction rope on the incline in safety.

In the second place, the sudden deflection of the traction rope from the guide wheel to the first carrying roller is such that attaching can only be done at one point, it being impossible to force the bucket by hand in advance of the lug when once the traction rope has entered the grip. This would also be avoided in the inclined terminal, but, in default of that, a swinging guide wheel has been attached ahead of the attaching point, making the traction rope nearly level for a distance of about 6 ft., which will allow the attachment to be made with ease.

This swinging guide supports the rope about 1 in. lower than does

the wheel on the bucket below the grip, and, as the bucket passes, it is pushed to one side, returning to its position as soon as the load has passed.

In this connection it may be pertinent to speak of the means adopted to get the material to the site of the terminal. The whole face of the mountain was covered with loose slate and shale, making anything resembling a road impossible without great expense; and at the foot of the slope was a chasm, through which a mountain torrent flowed. A little 8-H.P. hoisting engine was carried to the top, and then pulled up the cables.

Stretching these over low temporary supports, a tramway was improvised over which our terminal machinery, timber, buckets, etc., were all carried to the site, the engine being worked by compressed air from a neighboring mine. The permanent supports were then erected, and the cables transferred to their proper positions. The difficulties of this line in a climate where the snow had not entirely disappeared from the side hills in July, and where the rain was almost incessant during the entire season, are easier imagined than described.

Intervening Summits.—These are a fertile source of trouble, particularly in heavily loaded lines, owing to the severe strains put upon the bucket frames by the weight of the traction rope and its load.

It is evident that as each bucket surmounts one of these summits, it necessarily has to sustain temporarily the entire weight due to the loads on either side of it to the foot of the grade. This is to a limited extent remedied by frequent supports so placed as to form an easy vertical curve, that the rollers may catch the weight of the rope as quickly as possible. Heavy wear is also induced in the stationary cables at these points, and it frequently becomes necessary to construct a continuous trestle over the summit, and substitute a solid rail for the standing rope, on which the carriages may travel. Examples of these summit curves are the Guanecori Tramway, Durango, Mexico, and the Benners Bay Tramway, near Seward City, Alaska. Two especial examples are those of the "Bunker Hill and Sullivan" line, at Wardner, Idaho. They are both trestled and furnished with rails, and are snow-shedded for winter protection. The profile (Plate V) shows the construction.

They were originally built with the rails supported on the iron

hangers, secured to 6 x 8-in. hanger timbers in the way ordinarily employed in terminals. It was found, however, that these timbers gave down under the load, and they were re-enforced by 8 x 10-in. timbers placed above them, to which the original timbers were connected by yokes of 2 x ½-in. iron.

Intervening Hollows.—These, when of considerable width, frequently become another annoying feature in tramway building.

The ropes should be supported at either end, in such a way that no sharp angles will occur; and, generally speaking, it is better that in really long spars the standing ropes should be, as nearly as possible, independent of the rest of the line. This is especially the case when the two extremities of the span are approximately on a level. In such a case a tension station should be put in at the lower, and an anchorage at or not far from the upper, end; and the size of the ropes should be greater and the tensions higher than for the supported portions of the line.

The writer has found, in his own practice, that, where the conformation of the ground will permit, long spans, properly adjusted, are a positive advantage to a tramway line.

The reasons for this may be summarized as follows:

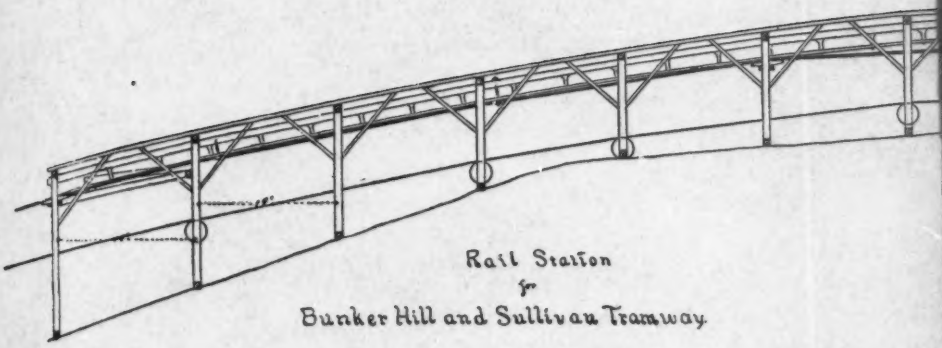
First, and manifestly.—A more regular grade line is attainable than where the line is broken to suit the conformation of the ground.

Second.—The points of danger of wreckage on these lines occur at the supports, and are due to supports out of line or misplaced saddles, against which the passing carriages may strike. The writer has never known of an accident occurring on a clear span, except through failure of the grip, with which the span has nothing to do.

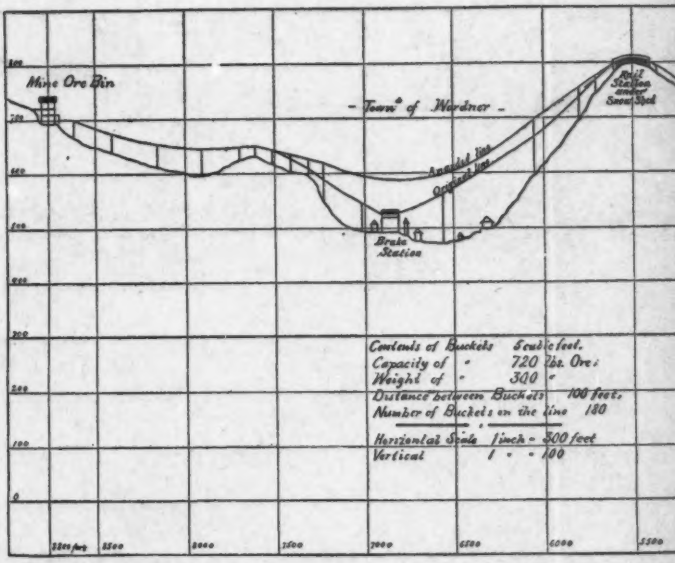
Third.—The wearing points on the carrying cables are, of course, only at the supports. A reduction in the number of these points is, therefore, manifestly a benefit to the line.

Fourth.—The reduction of the number of supports to be inspected and kept in repair is a reduction in expense of maintenance, and therefore desirable.

In designing these long spans, it becomes necessary to alter the form of support at their termini in many cases, to avoid undue wear upon the stationary cables at these points. The writer has obtained very good results during the past season by attaching two caps instead of one to the top of the towers, and so setting the saddles as to



Rail Station
for
Bunker Hill and Sullivan Tramway.


Mine Ore Bin
- Town of Wardner -
Rail Station and Tram Shed
Bridle Path
Aerial line
Brake Station
Contents of Buckets 5 cubic feet.
Capacity of " 720 lbs. Ore.
Weight of " 300 "
Distance between Buckets 100 feet.
Number of Buckets on the line 180
Horizontal Scale 1 inch = 500 feet
Vertical 1 " = 100

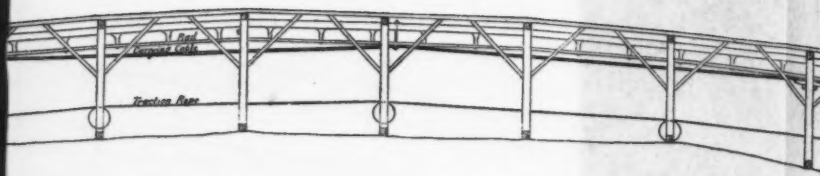

Rail
Carrying Cable
Traction Rope

Fig. 1.

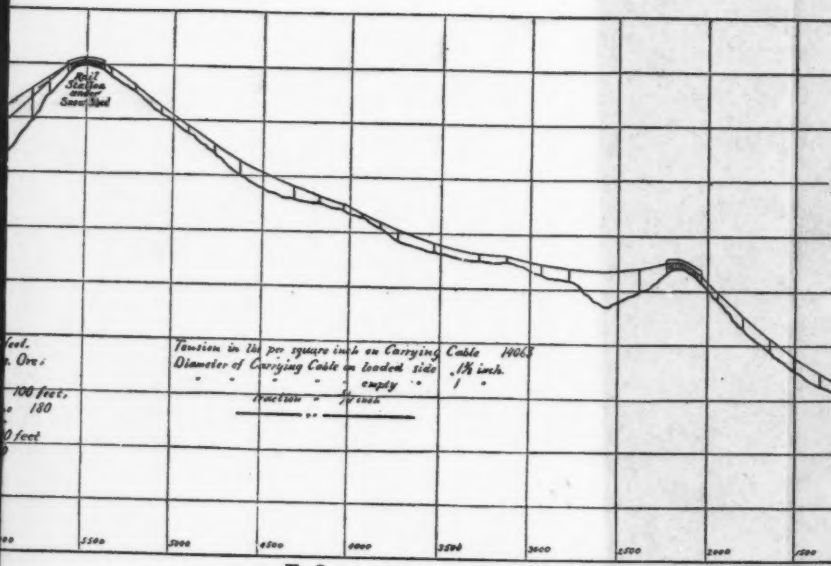
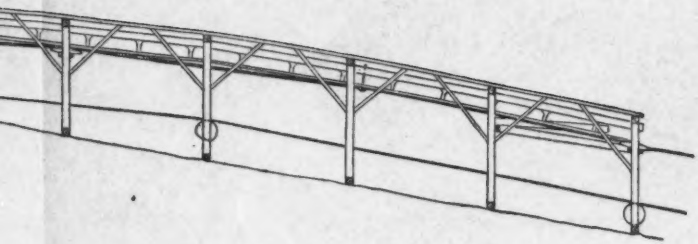
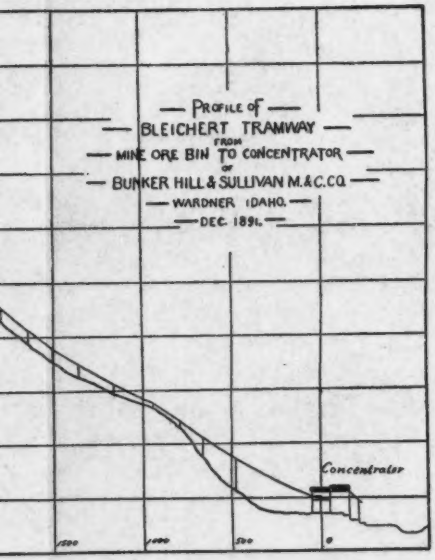

Rail
Station
above
Snow Mark
Tension in lbs per square inch on Carrying Cable 14063
Diameter of Carrying Cable on loaded side 1⅛ inch.
" " " " empty " 1 "
Traction " 1/2 "
3500
4500
5000
3500
3000
2500
2000

Fig. 2.




PROFILE OF
BLEICHERT TRAMWAY
FROM
MINE ORE BIN TO CONCENTRATOR
OF
BUNKER HILL & SULLIVAN M.&C.CO.
WARDNER IDAHO.
DEC. 1891.
Concentrator
1500
1000
500
0

present a supporting arc of some 40 ins. in length. In case of very long spans this could be still further increased in length by the addition of still another cap; but it has been found that the 40-in. arc, with a radius of 5 ft., is ample for spans of 1 500 ft. in length.

In the case of the Bunker Hill and Sullivan line, which for a time seemed to defy any efforts to make it work smoothly, the trouble disappeared when the changes were made which are indicated on the profile. In this case the line had been held down where it crossed Milo Gulch, and the traction rope cut at the lowest point, making practically two lines of it.

In remodeling it, this intermediate station was taken out and a span of 1 180 ft. carried entirely over the gulch. The traction rope was made continuous, and the good effects were at once apparent.

The benefit derived from the long span may be inferred from the fact that on the occasion of the breaking of the main driving shaft at the upper end, and the consequent running away of the line, not a single bucket was dropped from the long span.

This line is furthermore a good example of the capabilities of these lines. Although by no means one of the heaviest in equipment, having only 5 cu. ft. buckets as carriers, it has for a year and a half carried easily its 50 tons per hour and made an average record for months of 450 tons per 10 hours' work, at a cost of about 16 cents per ton, which, taken in connection with the high rate of wages paid in that camp, is certainly very cheap work. This takes into account only the ore delivered, and does not include the return transportation of supplies, timber, etc., which has frequently run up to 30 or 40 tons in a day.

These few notes are submitted in the belief that a more general understanding of the requirements and capabilities of these lines may lead to further improvements in their design. While in no sense competitors with surface transportation for general freight, they might easily be made valuable adjuncts for special products, and in cases where the nature of the country is unfavorable to surface lines.

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718.

(Vol. XXXII.—July, 1894.)

STEAM AND ELECTRIC CABLEWAYS FOR LOGGING AND CANAL-BOAT TOWING.

By RICHARD LAMB, Assoc. M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

The antiquity of the carry-log that most of our lumber-men are using to-day is undoubted. The writer has, at least, seen exceedingly old illustrations showing big two-wheel carry-logs drawn by oxen, which would serve to show how logs are hauled at the present time.

It is true that during the last 50 years or so narrow-gauge light rail steam railroads have been very generally used in logging, but these have been for main lines to take the place of rivers, and they do not displace altogether the old style carry-logs, for they are still used to bring the logs to the railroads.

Of course, in countries where snow is of sufficient duration to admit of sledding, the carry-log is displaced. As much as 36 000 ft. of white pine has been hauled at one time on a sled by one pair of horses. It is, therefore, evident that sleds are cheaper than wagons for logging.

The principal question that the logging engineer has to consider is, how to cut the trees and get them to convenient points for transportation at the least expense. On firm land, the methods employed are carry-logs with oxen or horses, damming the small streams and driving the logs during freshets, and in northern countries sledding. Water flumes, made of wood, are used to advantage in the West.

The Butters system of one-span steam cableway is also used, but only for a maximum distance of 700 ft. Cableways have been tried with horses for the motive power. The fact that the contour of the ground needs to be practically level has caused all such horse cableways to be abandoned. The mechanical principle which operates against cableways where the logs are hauled by horses is that the direction of the force should be practically in the line of what we might call the axis of the horse passing through the hips.

When the land slopes, making considerable of an angle with the direction of the cable, a resultant force is created which equals the weight of the horse and he ceases to be able to pull the log. Any system of steam or electric cableways should be designed with reference to overcoming this difficulty, by making the line of the pulling cable always parallel with the bearing or main cable.

Necessity has caused a great number of experiments to be made in logging in wet or swampy ground. The Butters system is used to advantage in swamps, where the haul is short, and is largely used throughout the South.

Mr. Spencer Miller described this system in a paper before the Society, which was recently published. That gentleman made a number of improvements upon this system.

Mr. Dickinson, of the Trenton Iron Company, has invented and patented an ingenious system of cableway for logging in swamps, and the plant is an improvement over the Butters system in that it is designed to go further into the swamps. It is put up like trolley wires, the trees being used for the upright supports, which in the trolley system are on either side of the street. A movable block is placed upon the supporting cables, and upon these blocks the main cable is hung. This has not been put into practical use however.

The difficulty with this system is the necessity of finding the trees in just the positions needed, and the fact that the hauling cable has no support, but drags upon the ground.

What is known among lumber-men as a "pull boat" is quite generally used in the cypress swamps of the South. It is designed on the principle of "main strength and awkwardness." A steel cable is carried into the swamps and passed around a large sheave, and a ½-in. cable is attached to the end of a larger cable. A large double drum engine is used. By winding in the ½-in. cable, the larger cable is pulled out into the swamp, and by attaching the logs to the larger cable and winding it on the drum the logs are hauled in.

This system is limited to the length of rope that can be conveniently wound on the drum.

The problem that confronted the writer was to design a cableway that could be operated at least ½ mile, with the power placed upon a boat or car located at a navigable point. It should gather in the logs for at least 500 ft. on either side of the cableway proper, and by its means bring the logs to navigation at a reasonable cost for operation. It was necessary that such a system should be easily and cheaply moved from place to place as the total area of forest to be cleared at any one setting would not require much time. Trees had to be used as supports as they are the only practicable foundation to be found in a swamp. It was evident that any steam system would have to be worked in practically a straight line.

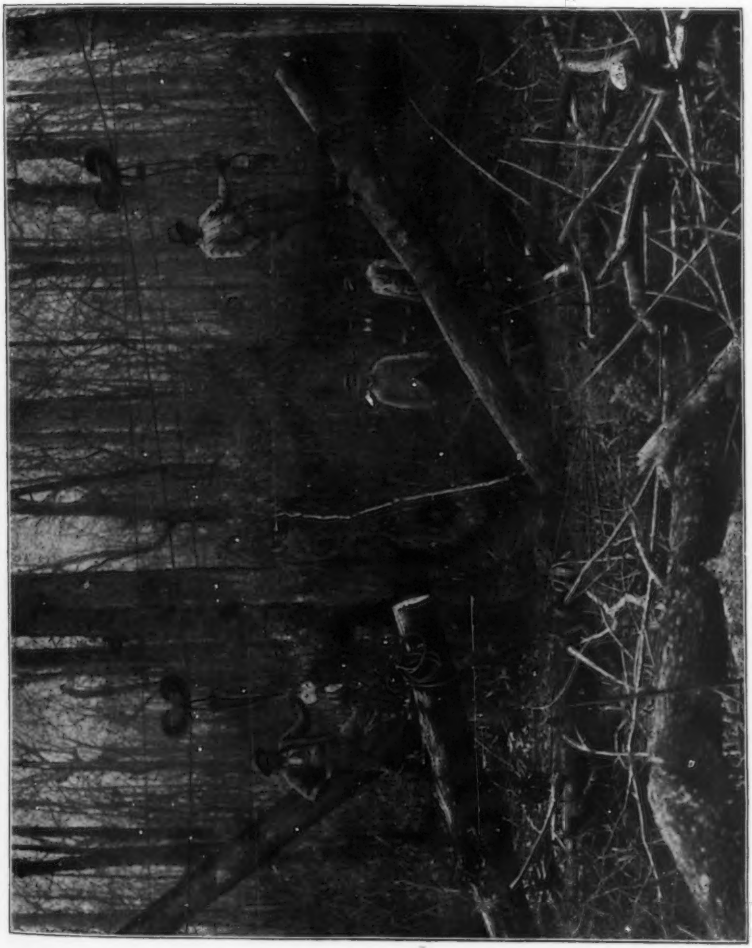
To attempt to find trees in a straight line would be difficult if the distance apart was not great, but after running a number of lines, it was found that in a forest of ordinary density a practically straight line could be gotten with trees at from 100 to 225 ft. apart.

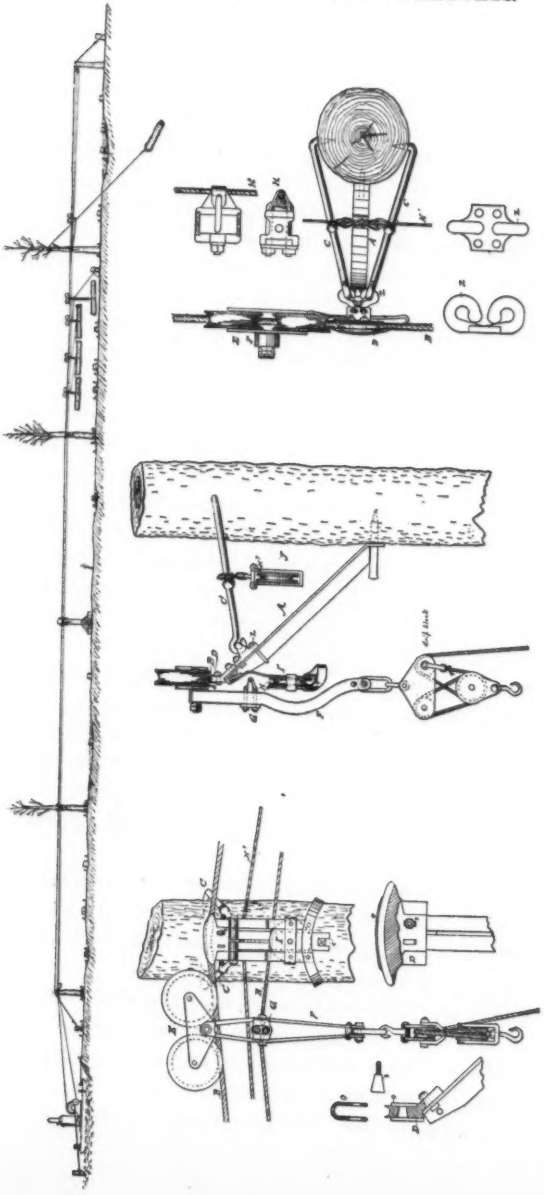
The writer's system was designed for long spans in consequence.

The accompanying drawing (page 47) shows the T iron brackets that were used for passing by the trees, and for supporting the cable. The end of the T iron bar straddles an 1½ × ½-in. iron pin driven into the tree at a height of about 13 ft. from the ground. The dogs on the ends of the arms attached to the T iron bar are driven into the tree on either side, and a chain wrapped around the arms and held from slipping by upset knobs keeps the arms from spreading. This chain also serves to hold an iron snatch-block.

A swinging sheave is hung from the end of the T iron bar on which is an iron band curved rearwardly and downwardly, which acts as a fender and also replaces the hauling cable, should it become disengaged from the hanging sheave. The steel saddle at the end of the

PLATE VI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 718.
LAMB ON STEAM AND ELECTRIC CABLEWAYS.





T bar is provided with boiler steel U plate. Two wedges pass through the U plate and saddle in opposite directions to each other. By means of these wedges the U plate clamps the main cable rigidly to the saddle.

On the head tree two sheaves are placed, one on either side, and on the tail tree a 2-ft. steel sheave is chained.

The endless ½-in. pulling cable, made of 19 strands of steel wire, is passed through the sheaves on the head tree and on the brackets and around the large sheaves on the tail tree. Two turns are made around a 2-ft. elliptical grooved sheave, run by a 25-H. P. engine for ½-mile line. The engine is made reversible.

After the ½-in. cable is out, the main cable is hauled into the swamp by steam-power by means of the hauling cable.

The main cable is 1 in. in diameter and is of patent interlocked steel, which gives a better wearing surface. This cable cannot be made in longer lengths than 450 ft., but these are easily joined together by a patent coupling, over which the car passes readily.

The 450-ft. sections are hauled out before coupling them together. Any distance of cable can therefore be very easily pulled out into the swamp.

A false saddle is used in putting the cable on the brackets, and has vertical flanges, to keep the cable in place; and rollers are on either end, to reduce friction when hauling the cable taut. After the cable is clamped to the saddle, the false saddle is removed.

The cars are made with a hanging frame supported by a horizontal axle passing between the wheels upon which it swings. By this arrangement the hanging frame can remain vertical even when the car is climbing the steep grade of the catenary on approaching the saddle and when passing over it.

The hauling cable is attached rigidly to the frame of the car at a point located so as to clear the swinging sheave. It will be noticed that the hauling cable is practically parallel with the bearing cable at all parts on the line.

A Detroit grip block is attached to the end of the swinging frame, to which is hung a pair of logging tongs. By securing the bight of the rope of the grip block about a tree or stump and pulling in on the car by means of the hauling cable, the two blocks are made to meet and thus haul up the log. The grip keeps the blocks from parting

PLATE VII.
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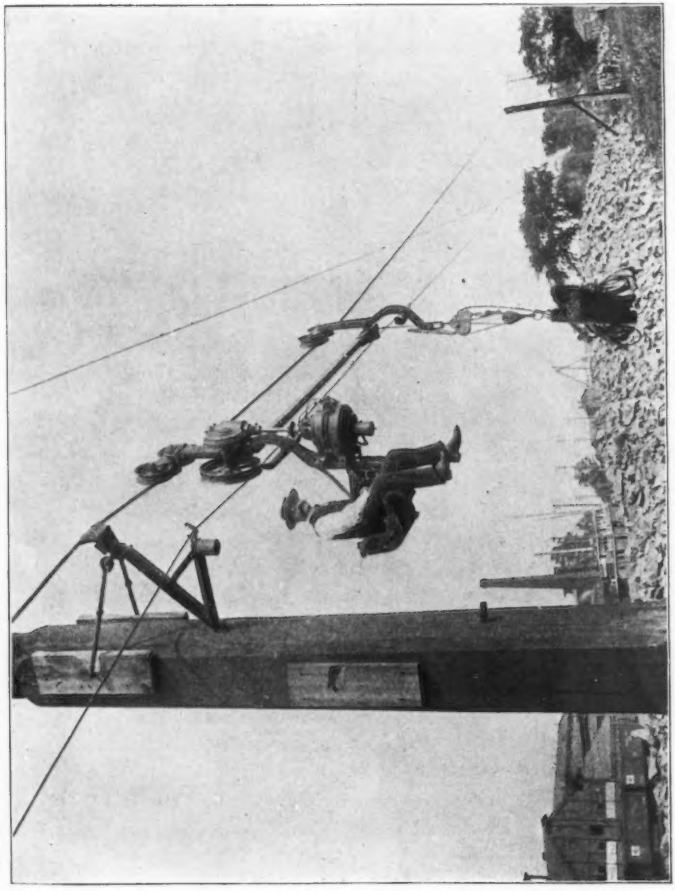
LAMB ON STEAM AND ELECTRIC CABLEWAYS.



until it is desired to drop the log, when by pulling a string on the grip the log drops. This does away with the difficulty heretofore experienced of the necessity for a separate cable and a separate drum on the engine to haul the log up to the car.

In order to haul the logs from either side up to the cable, trees are chosen within about 15 ft. from the cable, or the tail or bracket trees are used, up to which to pull the logs. A 10-in. sheave is chained as high up the selected tree as may insure sufficient stiffness. Another 10-in. sheave is chained to the tree a little below the level of the cable and a third 10-in. sheave is fastened in a horizontal position to the cable at the end of the bracket, or at the end of a temporary strut placed between the tree and the cable.

A ½-in. cable is attached to the car and the loose end passed through the horizontal sheave; thence through the lower sheave on the tree; thence up the tree, and through the upper sheave.

A pair of double tongs made to operate in lines at right angles to each other are attached to the end of the cable and carried into the woods. The tongs are clamped to the end of a log and act as a fender or guide, to prevent it from bringing up against stumps or other obstructions when being hauled into the cable. By hauling in the car, which is attached to the end of the skidding rope, heavy logs are easily dragged to the cable. When the road under the cable is very rough, the logs to be hauled by the main cable are swung from their centers and joined together with dogs and chain, to keep them in line; but in general it is found that simply attaching tongs to the ends of the logs and raising them from the ground and letting the other ends drag answers all purposes.

Not counting the tree cutters, an engineer and fireman (who also cuts wood for fuel when not firing) two tongmen, one loader and one unloader, in all, six men, constitute the crew. On dry land 40 000 ft. per day can be hauled; in the swamps, 25 000 ft. per day can be gotten out. The saving in cost of hauling over any other method of logging is obvious, but this system also saves money in that it gets out timber that heretofore has not been accessible.

For persons operating a logging railroad or on a river where from ½ to 1 mile of cableway is sufficient, the above-described steam logging system is sufficient.

It became necessary, however, to design a system that practically

would not be limited as to the distance it could be operated. To this end an electric cableway was built. Investigations showed that other systems of telpherage had been tried, but few had been put into practical use, owing largely to the expense of having to make the supports close together, so that the cable might be perfectly taut, as the limited friction area of the wheels on the cable, and the inclination of the catenary near the supports, made it impossible for the car to climb the incline. The power being applied to the wheels, and depending upon traction, they would slip down the grade while they were revolving to make them climb up. Again, there could be no brake to keep the car from slipping too fast after passing over the saddle. As economy and ease in moving depended upon being able to use a few supports, or, in other words, long spans in the forest, it was evident that no system of traction was available. The direction of the force should be parallel to the bearing cable. This suggested the use of a ½-in. cable, made fast at both ends, to be supported at the tree brackets by a narrow saddle, so designed as to enable the cable to change its course and not to become disengaged when the car passed over it.

The motor is made with the car like the steam cableway before described, with a hanging frame having attached to it an elliptically grooved sheave which is revolved by means of a newly patented worm or wedge-gearing, driven by a 5-kilowatts electric motor with vertical shaft, all attached to the swinging frame of the car. By taking a couple of turns of the ½-in. cable around the elliptical grooved sheave, when the electric motor revolves the gearing, the sheave winds up, and at the same time plays out on the ½-in. cable, thus pulling along the car.

When it reaches the bracket, the small cable is lifted from the saddle momentarily, and the car can take a new course. Hence we are not limited to operating in a straight line. The main cable is used as the electrical conductor. It is insulated at the brackets by insulating material placed between the saddle and the T iron bar, and the current is prevented from passing down the frame of the motor by insulation at the point on the frame where the axle-box joins the frame proper. The points of insulation are provided in their construction with hoods to shed water.

The worm or wedge gear deserves especial mention. It was invented in 1891 by a Mr. Welsh, of the Glen Cove Machine Company.

PLATE VIII.
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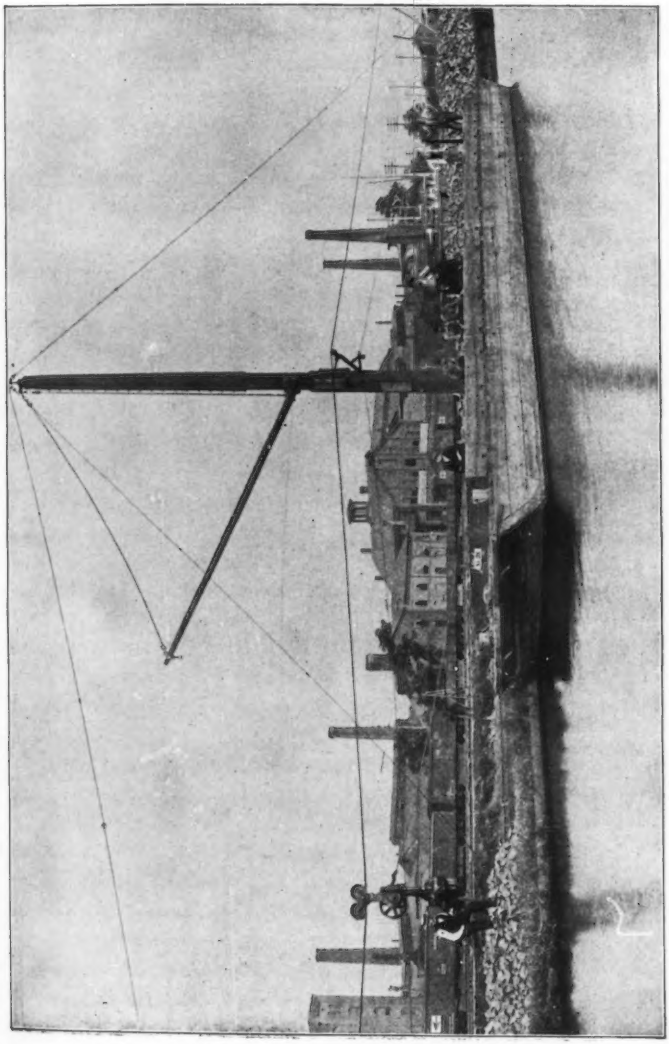
LAMB ON STEAM AND ELECTRIC CABLEWAYS.



It differs from an ordinary worm gear in that it has more than twenty times the bearing surface of an ordinary worm and wheel, moves two teeth of the gear wheel at each revolution of the worm, and works on the principle of a wedge rather than an incline plane. The worm gear, especially made for this electric motor, is designed to work both ways, and has ball-bearings at either end of the worm, to lessen the friction and thrust. The gear wheel, worm and ball-bearings are encased in a jacket filled with oil. Thus the minimum loss in power is effected between the electric motor and the elliptical grooved wheel. The gearing was necessary in order to lessen the speed, as the electric motor is run at 1 840 revolutions per minute, giving a speed to the motor proper, with the gearing, of 6 miles per hour, which is the desirable speed for logging purposes. The current is taken from the main cable through the wheels, thence through the axle to the axle-box of the hanging frame. Here an insulated copper wire connects it with the rheostat. The return current is passed through the axle of the elliptical grooved wheel; thence on to the ¼-in. wire to the brackets; thence to the ground.

The rheostat is made to carry the current through it, as well as to regulate the speed and reverse the current.

In the system now built 220 volts are used. The trial was made at the works of the Trenton Iron Company, Trenton, N. J., along the banks of the Delaware and Raratan Canal. It was found that heavy logs could be pulled from a distance up to the cable by the same method as employed in the steam system, and that logs could be carried in the same manner as stated in the description of the steam rig.

When two motors are used, the empty cars are switched off the cable, and motors are exchanged, the motor which hauled the empties taking back the loaded ones, and *vice versa*. This system of electrical cable-way can be used for an endless variety of purposes.

A valuable service for this new motive power was tested, viz., towing canal boats. It will be obvious that a cable can be located on a towpath, and at either end of the canal can be built sheds in which there would be a large number of motors ready to go out. On application of a canal boat captain, a motor will be allotted to him, and he will proceed, towed with a tow-line having insulated wires in the center of same. The rheostat will be located on the canal-boat.

The wires in the hawser can be easily attached to or detached from the rheostat. When a boat meets another, they change hawsers and consequently motors, and proceed. Two lines of bearing cable would do away with this trouble.

The cheapness with which this system can be built and operated would insure the saving of thousands of dollars in the operation of such a canal as the Erie, especially as that canal has at its disposal the almost limitless electrical resources of the great Niagara cataract.

DISCUSSION.

SPENCER MILLER, Assoc. Am. Soc. C. E. (by letter).—The "pull-boat" system referred to by Mr. Lamb is known as the Baptist plan. The hauling power is an engine made after the manner of the cable railway engine, and is located on a boat, which may be floated in the bayous or canals. The hauling cable reaches into the woods 3 000 ft., passing round a sheave wheel as the far end, known as the tail tree.

An important element of the Baptist system for handling logs is the use of a hollow cone, made of steel, whose base is about equal to the diameter of the log being hauled. Through the apex of this cone a chain is passed with tongs or dogs on the end, which are secured to the log. This chain is made fast to a clamp on the endless rope, and they are thereby drawn in over the surface of the ground at a rate of speed of about 500 ft. per minute. Whole trees are pulled in this way.

The chief value of such a device lies in the fact that there are the smallest number of parts to get out of order and need attention. The cone serves to clear the log over any obstacles, such as stumps, etc. It requires, of course, a large amount of power, which means a large engine has to be purchased, but inasmuch as the waste wood is burned, the cost of fuel is a trifling matter.

The Baptist plan suits some conditions better than the Butters, and it is reasonable to suppose that Mr. Lamb's system, which extends still further, will have its place.

My observation leads me to expect that a great many locations will be better served with that machine than with anything else. However, I would like to hear from Mr. Lamb a year from now, after he has had the machine in use for that length of time, under the conditions which he will find in the woods. I have not had the pleasure of seeing this machine as yet.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

719.

(Vol. XXXII.—July, 1894.)

BRAFFORD'S RIDGE TUNNEL.

By CHARLES W. STANIFORD, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

This tunnel is located nine miles from Corbin, Ky., on the Cumberland Valley Branch, Louisville and Nashville Railroad, the first 32-mile division of which, from Corbin to Pineville, Ky., was built in 1887-88, under the supervision of the writer as Division Engineer, assisted by Mr. M. E. S. Posey, Resident Engineer of the 2d Residency (including tunnel), and under the general direction of R. L. Cobb, M. Am. Soc. C. E., as Chief Engineer of Construction, Louisville and Nashville System.

The line for the whole length of the division follows very closely what is known as the old "Wilderness Road," celebrated as the trail taken by Daniel Boone on his first entry into Kentucky, at Cumberland Gap nearby, and also as the marching and camp ground of both armies during the Civil War. In many places this road had to be changed and relaid higher on the hills, away from the Cumberland River, in order to give a footing for the railroad, where it is hewn out of the river cliffs.

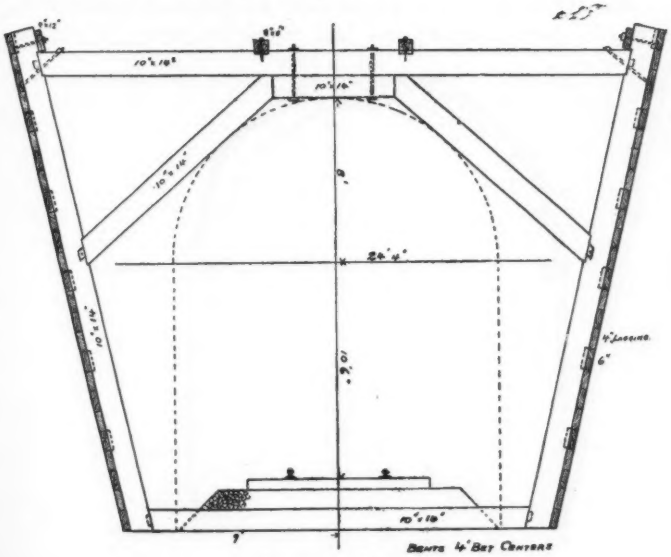
The Gap at Brafford's Ridge, both from a geologic and topographic

standpoint, was unfavorable for the construction of a tunnel. The rock encountered at the portals was a brittle, heavily laminated shale, which, although easy to work, disintegrated rapidly on exposure, rendering support, temporary or permanent, necessary. The overlying material, which would have to be penetrated by either an open cut or the approach cut to a tunnel, was a wet gravel with many boulders, very treacherous to work, and hard to maintain. Steep rising slopes adjacent to the line in this material (see Plate IX), made it undesirable to go down so low as the approach cut to a tunnel would necessitate.

It seemed that the thing to do would be to raise the grade high enough, not only to avoid a tunnel, but to get a reasonably light cut, even at a great increase in the maximum grade. The formation of the surface on each side of the ridge in this vicinity made it impracticable to do this, as the western approach was an elevated, but very flat country, giving no supporting ground on which to develop a grade line; while on the eastern side of the hill the ground dropped off very rapidly, so that on our maximum grade of 66 ft. per mile we reached the bottom lands near the Cumberland River, in about three miles from the summit.

A tunnel being necessary, it was decided to line it with timber at first, and to replace the lining in time with more permanent support if necessary. In the east approach cut, after working into this soft material with its steep slope, it was found that a self-supporting cut was impossible, and timbering was commenced about 300 ft. from the portal, with a section as shown in Fig. 1. The upper portion of the cut was taken off first, in order to give an entry into the heading (Plate IX), sloped only enough to stand temporarily. At the same time a force started at grade, sloping 1 to 1 as far as possible. The side batter posts were then placed as soon as sufficient material had been removed to get them into position, after which the straining beam, braces, lagging, etc., were framed in place, and the rear filled in and packed evenly on each side. The timbering was started by spacing the bents 6 ft. between centers, but after an exceptionally heavy rain, lasting several days, the side batter posts commenced to bend under the pressure. Only six bents had been put in at this time, so the distance between centers was reduced to 4 ft., after which no section of the timbering showed any signs of weakness, and the six bents mentioned were re-enforced by an extra bent between each.

It was intended to work most, if not all, of the tunnel from the east portal, so as to avoid the water which would back up in the down grade on the west side, and also to take advantage of this favorable grade for the transport of material. It became evident, however, that if so prosecuted, the work would not be finished with the balance of the road, owing to trouble experienced with water in the west approach, and with the timbering on the east side.



Section in Approach Cut

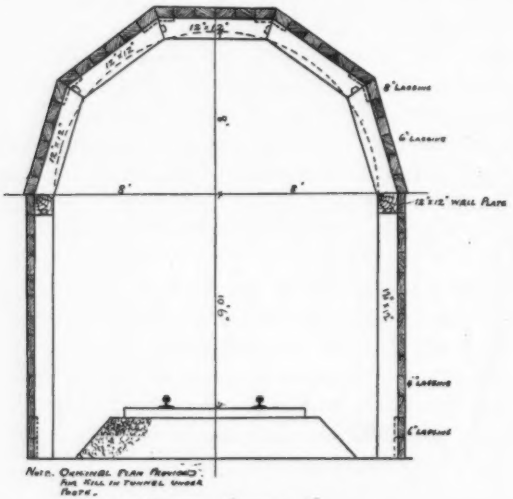
Fig. 1.

The west approach was worked by taking off the surface of the cut and running an incline to strike the heading as soon as possible. After the headings had met, much of this cut remained to be taken out, so that, in order to commence on the bench at each end, another drift was inclined to meet grade of the tunnel near the portal. This material from the bench was hauled out on a narrow berm, along the crest of the cut.

When the work was near completion, but before the benches had met, it was seen that although the tunnel would be finished on time,

the approaching track-laying would be delayed by the west cut not being out; another bench was started at grade in this cut near the portal and worked westward. This method of procedure formed a vertical face, and left no runway for the disposal of material, so a derrick was placed above the face on top of the cut, the rock hoisted in car bodies, then placed on other trucks, and hauled along the berm to the waste dump (see Plate IX).

The points selected for portals made the length of tunnel 843 ft., and the section adopted (see Fig. 2) was the five-segment roof,

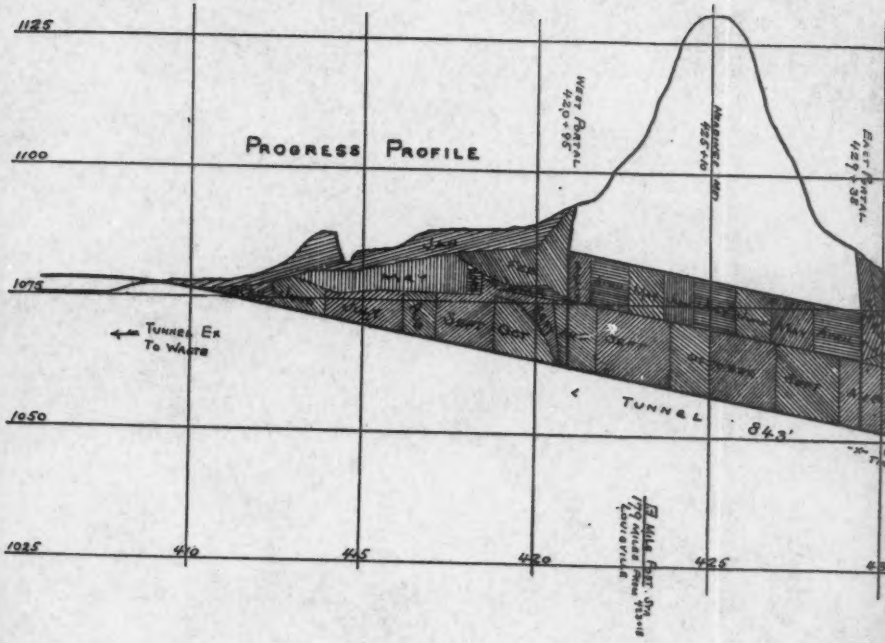


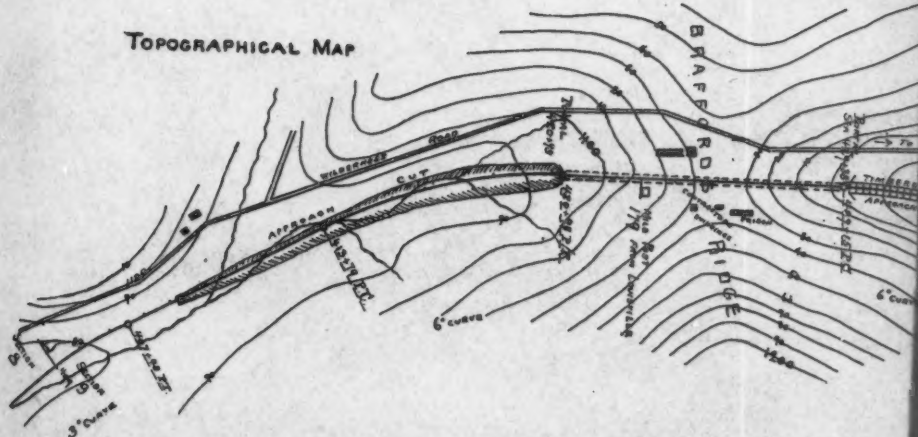
TUNNEL SECTION.

FIG. 2.

coinciding with an 8-ft. radius circular arch at the joints, with bents 4 ft. between centers. Roof ribs, side posts and wall plates of 12 x 12-in. timber, mortised and tenoned at upper joints in roof, and at upper end of posts into wall plate. Lagging, 6 ins. thick in roof, except at joints where 8-in. was used, with 2-in. dap; on sides, the lagging was 4 ins. thick except two lower courses where 6-in. timber was used with 2-in. dap.

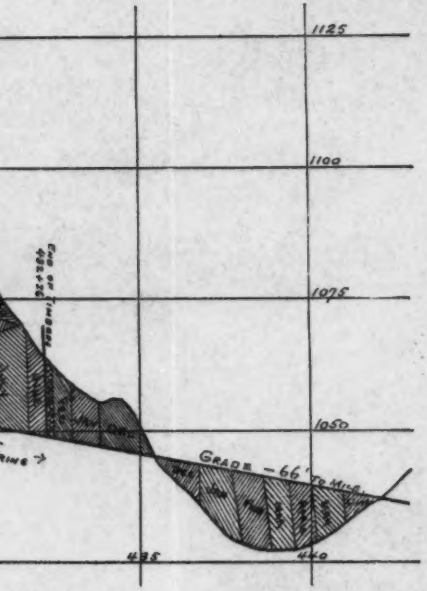
All drilling was done by hand, the holes being placed so as to blast out the interior section without disturbing the outside limits or

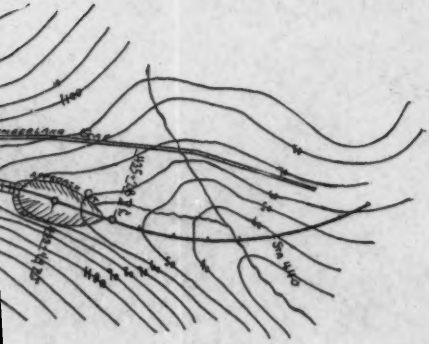

PROGRESS PROFILE
1125
1100
1075
1050
1025
410
415
420
425
WEST PORTAL 420+95
HIGHEST HILL 425+75
EAST PORTAL 423+38
TUNNEL EX TO WASTE
TUNNEL
843'
3 MILES EAST OF 7TH ST. LOUISVILLE


TOPOGRAPHICAL MAP
BRADFORD RIDGE
WILDERNESS ROAD
CUT
APPROACH
TUNNEL
6° CURVE
3° CURVE

End of Timbers
432+26
East Portal
429+38
Hardinge Mt.
425+10
West Portal
420+95
Tunnel 843'
Cut Through
Mile Post Sta.
179 Miles from Louisville
Bradford Ridge
Mile Post
179
From Louisville
Tunnel
420+79
432+38 P.T.

PLATE IX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 719.
STANIFORD ON BRAFFORD'S RIDGE TUNNEL.





the roof. Small holes and charges were then carefully placed and fired to try to approximate the shape of roof required. This was usually accomplished, and at the same time taking out very little material outside the normal section. A blast so shattered the rock, however, that in order not to bring down any more than was absolutely necessary, the timbers and lagging had to be placed as soon as enough space had been mined for them, after which the void space in the rear was carefully packed with rock laid dry.

MONTHLY PROGRESS IN HEADING.

Month ending—	WEST END.		EAST END.		Both ends. Total.	Both ends. Monthly.	Feet remaining.
	Total.	Monthly.	Total.	Monthly.			
March 31st.....	65	65	...	...	65	65	778
April 30th.....	180	115	138	138	318	253	528
May 31st.....	285	105	258	120	543	225	300
June 30th.....	355	70	358	100	713	170	130
July.....	415	60	428	70	843	130	...

The headings were commenced March 15th, and finished July 15th, 1887. The size approximated a semi-circle of 9½ ft. radius, giving about 5½ cu. yds. per linear foot.

The maximum progress in heading for one month in east end was 138 ft.; average monthly progress about 122 ft., or 641 cu. yds.

The maximum progress in heading for one month in west end was 115 ft.; average monthly progress about 104 ft., or 546 cu. yds.

WEEKLY PROGRESS ON BENCH.

Week ending—	WEST END.		EAST END.		Both ends. Total.	Both ends. Weekly.	Feet remaining.
	Total.	Weekly.	Total.	Weekly.			
August 13th.....	15	{3 days / 15}	...	...	15	15	828
August 20th.....	40	25	21	{3 days / 21}	61	46	782
August 27th.....	75	35	45	24	120	59	723
September 3d.....	92	17	92	47	184	64	659
September 10th....	136	44	152	60	288	104	559
September 17th....	184	48	190	38	374	86	469
September 24th....	232	48	235	45	467	93	376
October 1st.....	274	42	274	39	548	81	295
October 8th.....	328	54	321	47	649	101	194
October 15th.....	391	63	380	59	771	122	72
October 19th.....	423	{3 days / 32}	420	40	843	72	...

The bench was started August 10th, and finished October 19th, 1887; size about 13 ft. x 19.66 ft., or 9.58 cu. yds. per linear foot.

The maximum weekly progress on bench at the east end was 60 ft.; maximum at west end, 63 ft. The average weekly progress for total of both ends was about 84 ft., or 805 cu. yds.

The headings met with about 0.02 variation in alignment, and practically no difference in grade. The roof timbers all came to true even bearings, showed no settlement or warping, except in one place near the portal at the east end, where, in starting the bench, too long a section was left unsupported before putting in the plumb posts under the wall plate, causing a slight settlement and outward movement of roof towards portal. This was remedied by placing longitudinal bracing outside the tunnel, which was afterwards taken away when the timbering in the cut came flush with the tunnel portal. All posts, lagging, etc., were after this put in as soon as enough rock had been removed for them, avoiding any further trouble from settlement.

White oak was the only available hard wood and was used for the lining in tunnel and approach. It was sawed and cut at temporary mills in the mountains, distant about one mile, then hauled to the work and framed to sizes outside the tunnel.

All labor at the tunnel and approaches (except the actual work in framing timbers together, after they had been placed in position) was performed by Kentucky State convicts, the contractors having the lease of the penitentiary at Frankfort, and employing a certain number on railroad work, where they could be used to advantage in different parts of the State. The unsettled condition of the people in this mountainous country, and their aversion to the advent of the road, rendered it difficult to persuade the average colored laborer to remain long in one place, so that the question of labor, and how to keep it, was of the utmost importance to a contractor, who looked towards finishing his work in time to satisfy the company. For this reason the regular convict system, with the men always under perfect control, for day or night duty, rendered them almost invaluable for work at a tunnel in a country like this, where its delay meant the holding back of a whole line of road. They were worked in gangs of from 10 to 15 men under a foreman and guard, one guard at each portal protecting the tunnel, and were used elsewhere on this division only for work at bridge foundations, and in track-laying.

The writer will state in passing, that contrary to many newspaper and magazine articles he had read, criticising the system throughout the South, curiosity led him to inquire into the matter, and from personal observation at this tunnel he found the men (mostly colored) well treated, with comfortable quarters, plenty of plain but good food, and as a rule better contented than he had often seen convicts within prison walls. There were only two or three attempts at escape during the construction of the tunnel, and not any while track-laying was in progress, where the chance for successful escape was much greater.

The total cost of the work was as follows:

Tunnel.		
Excavation, 12 513 cu. yds. at $3 50	$43 795 50	
Packing, 1 309 cu. yds. at $2 00	2 618 00	
Timber, 415 344 ft., B.M., at $24 50	10 175 93	
		$56 589 43
Approach Cut—West Side.		
Earth excavation, 3 567 cu. yds. at 13½ cts.	$481 55	
Loose rock excavation, 8 331 cu. yds. at 50 cts.	2 915 85	
Solid " " 1 826 " " 70 cts.	1 278 20	
		4 675 60
East Side.		
Earth excavation, 7 216 cu. yds. at 13½ cts.	$974 16	
Loose rock excavation, 1 509. cu yds. at 35 cts.	528 15	
Solid " " 2 526 " " 70 cts.	1 768 20	
Timber, 302 569 ft., B. M., at $24 50	7 412 94	
		10 683 45
Total		$71 948 48

Mason, Hoge & Company, of Frankfort, Ky., were the contractors for the whole 32 miles, the first 10 miles, including tunnel, being sublet to Messrs. Mason & Dickey.

DISCUSSION.

JOSEPH STRACHAN, Assoc. M. Am. Soc. C. E. (by letter).—Some notes as to cost of work and method of tunnel driving pursued on the South Pennsylvania Railroad, gathered during the progress of that work,

from 1883 to 1885, may be of interest in connection with Mr. Staniford's paper on the "Brafford's Ridge Tunnel."

The residency with which the writer was connected contained the Kittatinny and Blue Mountain tunnels, known as the "Twin tunnels," on account of their close proximity to each other, there being only 750 ft. between their adjoining portals.

All four approach cuts were through shale rock of the Hudson River and Clinton formations, with 1 500 ft. of Medina sandstone near the middle portion of each tunnel.

No shafts were used in driving either of these tunnels.

The lengths from portal to portal were: Blue Mountain, 4 240 ft., and Kittatinny Mountain, 4 620 ft.

About 3 280 ft. in length of these tunnels was driven for double-track road with an extreme width inside of masonry, at the springing line, of 27 ft., and a height from rail base to soffit of 20 ft. 6 ins. The section was excavated 2 ft. below rail base for drainage and ballasting of track. Where masonry lining was used, the side walls were of second-class masonry, laid in cement mortar. These side walls were 2 ft. thick at springing line of arch, with a straight back and a face battering 6 ins. in a height of 10 ft. 3 ins.

A three-center brick arch, 2 ft. thick, was sprung from these walls, with radii of 10 ft. 9 ins. on the under side of arch, from the springing line at each side through 45° of arc, and a radius of 14 ft. 8 ins. through 90° of arc joined the upper ends of the arcs of smaller radius and completed the arch. Dry stone packing filled the space between the back of the masonry and the rock.

The west end of Blue Mountain Tunnel was the only place where pumping was necessary, the grades at the other points being sufficient to properly drain the tunnels.

At both ends of Kittatinny Tunnel and at the west end of Blue Mountain Tunnel the method of driving was with a heading carried 75 to 100 ft. in advance of the bench, which latter was at once taken out to grade.

At the east end of Blue Mountain Tunnel, while excavating for double-track road, the bench was run up grade for several hundred feet, the heading about 100 ft. in advance of this upper bench, and a third force followed, taking out the material to grade on one side of the tunnel, leaving a berm on the other side wide enough to allow the cars from the upper bench to carry the muck from the heading and the upper level, to the dump.

One or two men were detailed to follow the bench force and trim the roof, for a peculiarity of this shale was that what appeared to be a very solid roof would, after exposure to the air for a few days, disintegrate, and large chunks would occasionally fall, sometimes with serious results to the laborers in the tunnel.

A compressor plant for driving the drills was located at each end of Blue Mountain Tunnel.

For Kittatinny Tunnel a compressor plant was located in the valley between the hills, and a 3-in. iron pipe was run over to the westerly heading; the single compressor thus operating both ends of this tunnel.

The reduction from double-track to single-track section was made by sliding the half section for double track sideways for 11 ft. on to the other half section, thus reducing the width of the section to 16 ft., and its height to a little over 21 ft., the resulting section showing a pointed arch.

No masonry for single-track tunnel was built, but at the west end of Blue Mountain Tunnel timbering was used for both double and single-track sections.

Single-track rock section required an excavation of 10.7 cu. yds. per foot run. The heading in single-track tunnel was usually about 12 ft. wide, and from 6 to 7 ft. high.

The holes drilled for the "cut," as the first holes in the face of the heading are termed, were usually eight in number, four on each side of, and about 4 ft. from, the center line, and, vertically, about 2 ft. apart, 7 to 8 ft. deep, and the upper hole on each line from 3 to 4 ft. below soffit grade.

"Squaring-up" holes were arranged in a manner similar to those of the "cut," and the lines about 6 ft. each side of center line of tunnel.

An additional hole at the top of the heading on center line was drilled for a top enlargement, and two holes at about the level of the springing line of the arch, and within 1 or 2 ft. of the lines of tunnel section, were drilled for side enlargement.

The heading force drilled the "cut" and "squaring-up" holes, and a second force the top and side enlargement holes, while a third force of drillers took care of the bench.

The holes drilled for the "cut" were inclined toward each other about 30°, so that a wedge-shaped section of rock was blown out, and as little force as possible wasted one side of the center line in neutralizing the force from the other side. The holes for the "square-up" were inclined slightly away from the center line, to get all the "cut" missed. Four holes across the 16-ft. width of tunnel were drilled to blow down the material to the bottom of the tunnel. When the heading floor was carried quite high, the material between it and bottom grade would be worked in two lifts.

From observations taken, the amount of explosive used for the "cut" varied from 75 to 100 lbs., according to depth of holes. The explosive contained from 40 to 60% dynamite.

Through the shale rock about 20 hours were required from the

beginning of one cut to the beginning of the next, *i. e.*, for the drilling, loading and firing of the heading holes and setting up drills to begin again. Through the sandstone from 25 to 27 hours were required for these operations.

The prices paid for tunnel excavation were: Blue Mountain, double-track tunnel, $3 per cubic yard, and $3 45 per cubic yard for single-track tunnel. At the Kittatinny Mountain Tunnel the prices were $3 25 and $3 50 for double and for single-track tunnel respectively. Second-class masonry, $8 per cubic yard; brick masonry, $12 per cubic yard; dry packing, $3 per cubic yard.

Force account was taken each day over the entire work and an estimate of the cost of the work to the contractor was calculated and sent to the Division Engineer with the monthly estimate of work done.

From observations made during the spring and early summer of 1885, the total cost to the contractors for East Blue Mountain heading, in Medina red sandstone, dipping 75° west, with a section requiring an excavation of 10.7 cu. yds. per foot run, was $7 39, and for bench was $4 10 per cubic yard; average haul by cars, 2 800 ft.

At West Blue Mountain heading, through olive shale of the Clinton formation, dipping 70° west, the cost was $4 16, and for bench $1 63, with a tunnel section of 15.6 cu. yds. per foot run, and an average haul by cars of 1 700 ft.

At West Blue Mountain, through olive and red shales with 5% sandrock, dipping 70° west, and a tunnel section of 11 cu. yds. per foot run, heading cost $4 50, and bench $2 67 per cubic yard; average haul by cars, 2 200 ft.

At East Kittatinny, through olive shale with 5% sandrock, dipping from 6° to 30° east, and a very wet heading, with a tunnel section of 10.7 cu. yds. per foot run, the heading cost $4 69, and bench $2 42 per cubic yard; average haul by cars, 2 350 ft.

At West Kittatinny, through red Medina sandstone, dipping 84° east, with a tunnel section of 10.7 cu. yds. per foot run, heading cost $8 38, and bench $3 43 per cubic yard; average haul by cars 2 400 ft.

The above figures were obtained by observing, as closely as possible, the force account at the different points and estimating the interest on cost of plant and depreciation of same, cost of small tools, fuel, transportation and explosives used.

Weekly progress reports were issued from the office of the Associate Engineer at Harrisburg, and a file of these, running from July 4th, 1885, to October 10th, 1885, shows a maximum weekly progress in heading of 65 ft. at East Kittatinny, and on bench of 52 ft. at the same place. The average heading progress for seven weeks, just previous to the orders to close down, was about 21 ft., and on bench was 24 ft.

During the progress of the work, notes were taken along the side walls of the tunnels of the dip of the rock strata, their thickness and

location by stations, and this information was plotted on a large scale for record.

When the alignment of the tunnels had been carefully made, the length between portals was measured by lining in large stakes with a nail driven into the top of each and near enough together to measure with a 100-ft. steel tape the distance between the nails on the slope of the hill. Careful levels were then taken on the nails, and the horizontal distances between them calculated in the office and summed up for the lengths of tunnels.

It was not our good fortune, however, to be able to "check up" line and levels through these tunnels.

The work was abandoned November, 1885, the headings of the Blue Mountain Tunnel being then 1 180 ft. apart, and those of the Kittatinny Mountain Tunnel but 570 ft. apart.

I believe no further work has since been done on the South Pennsylvania Railroad.

Mr. William F. Shunk, of Harrisburg, was Associate Engineer, with Mr. Robert H. Sayre as Chief Engineer of this road, and William H. Atwood, M. Am. Soc. C. E. (now deceased), was Division Engineer over about 32 miles of very heavy work which included these tunnels.

W. M. HALL, M. Am. Soc. C. E. (by letter).—Having done much similar work to that described by Mr. Staniford, I have read his paper with interest. To me the points of most importance are, first, the progress made with hand drills; second, the method of timbering approach cut; and third, his comments on convict labor.

As hand drills were used throughout, of course, his progress was limited by the drilling. For that method I note his tunnel progress was very fair; and in this connection I wish to say that for short tunnels of less than 2 000 ft. length, where time is not a matter of the very greatest importance, that even in this age of machinery it is the best manner of doing the drilling. In saying this, I mean it is best for both the contractor, who wishes to take out the excavation at the least possible cost, and for the owner of the tunnel, who wants it completed in the most substantial manner at the least possible cost.

In these days of cheap explosives and machine drills the inclination is to put in holes from 6 to 9 ft. in depth. These deep holes often injure almost or entirely beyond repair what could with shorter holes be made a good substantial rock roof. They also make the breakage outside of the desired section excessive. With machine drills every tunnel foreman wants to take out just as deep a cut as he can "pull." We can all easily make limits for the depth of these holes, but getting such orders obeyed is a more difficult matter. With hand drills there is no incentive to put the holes deeper than about 5 ft.; and, therefore, the natural roof is shattered very little and a better, and in many cases a good rock roof, is obtained, which, with the use of deeper holes,

would have been ruined, necessitating timber or masonry lining. I believe, therefore, that the engineer who orders or allows plants of drilling machinery put on his short tunnels, except in cases of absolute necessity, is making a mistake.

I read Mr. Staniford's comments on the treatment of convict labor with much interest, and, although this method of employing convicts is so severely criticised by our press, and many of our statesmen, it appears to me far better for any State to make a convict pay for his support and other expense to the State than to further tax the State which he has wronged for the support which he should be made to earn. However, as this is only remotely an engineering question, I will not pursue it further.

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(Vol. XXXII.—July, 1894.)

ON THE MARKING OF STREET LINES.

By C. M. BROOMALL, Jun. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

The writer, being interested in the question by reason of his position as surveyor of a Pennsylvania town, has been collecting data regarding the various methods used in different cities throughout the country "to mark the street lines, what manner of range stones or monuments are used, their location, size, etc.; also what points are used as level benches and to what datum they are referred." The subject at first glance seems a small one to spend much time in investigating, yet when it is considered how much depends upon the unalterability of street lines, there is little doubt but that the experience of all city engineers will lead them to agree upon its importance.

In collecting this data, circular letters were sent to city engineers in all parts of the country. The number of answers received was, of course, in no manner sufficient to show the average practice, but it gave the opportunity of choosing from a large number that which seemed the best practical method, and it was for that purpose the in-

quiry was started. The following is a brief record, with comments, of all the different methods contained in the replies:

First.—The commonest method of marking street lines is undoubtedly by the use of ordinary stone monuments, granite or marble. The usual length of the stones is from 18 to 24 ins., although, as exceptions to the rule, it may be mentioned that the city of Milwaukee, Wis., uses monuments 5 ft. in length; the city of Wilmington, Del., 3 ft. in length; Memphis, Tenn., 3 ft. in length; and Portland, Me., 5 ft. in length. A large number of replies received mention them as being located at the intersections of the center lines of streets, while others have them near the side lines on 3-ft. or 5-ft. ranges. In the city of Erie, Pa., the stones are described as 1 cu. ft. in size, with a copper rivet inserted to mark the line. In Salt Lake City, Utah, the monuments are protected by brick boxes with cast-iron covers. In the city of Jacksonville, Fla., artificial stone monuments are used. The city of Portland, Me., uses monuments of granite 5 ft. long and 8 ins. square, on 3-ft. range lines.

Second.—Iron monuments are used in many cities. In Topeka, Kan., round wrought-iron pins 1 in. in diameter and 30 ins. long were originally used, but now cast-iron pins 1¼ ins. in diameter and 30 ins. long are used, the reason given for the change being that the latter cannot be easily pulled out. In other cities iron bolts are used 1 in. in diameter and only 1 ft. in length, driven at the intersections of the center lines of streets. In Memphis, Tenn., iron bolts are used 30 ins. long, with flat heads 2 ins. square, the whole protected by an iron cylinder 20 ins. long and 6 ins. diameter, covered with a heavy cast cover. The same city uses in addition hard limestone monuments 6 ins. square, 36 ins. long, on 4-ft. ranges. The city of Albany, N. Y., has a system of iron monuments with many good points. A detailed description of it given by the City Engineer, Horace Andrews, M. Am. Soc. C. E., states that they use a 5-ft. length of double-hubbed, extra heavy 3-in. soil pipe of tarred cast iron, weighing about 50 lbs. Into one of the hubs a brass cap, about 3 ins. in diameter and 1¼ ins. thick. is leaded, having upon it the inscription, "Albany City Monument." This cap weighs about 2 lbs., and in its center a small hole is drilled, to mark the line.

Third.—Another kind of monument which is interesting and worth description is that used in Salem, Ore. Each monument consists of two dressed stones set vertically one above the other, the lower one

being 5 ins. square and 10 ins. long, and the upper 5 ins. square and 24 ins. long. One quart of charcoal is placed at the junction of the two stones where one stands upon the other. Both stones are marked with a cross and centered. The monuments are set at the intersections of the center lines of streets.

Fourth.—The number of different bench marks used is large. The regular stone or iron monuments of the city, water tables of buildings, stone foundations, hydrants, door sills of buildings, stone copings, curbing, fire plugs, square-headed bolts in the roots of trees, etc.

Fifth.—The different data used are almost as numerous. Of course, the majority of them are purely arbitrary. Sea level is often used, and cities on the lakes use high-water level of the lakes; and others use the water level of such river as they may be situated upon. The datum at Cleveland, O., was established in 1854 as a mark on the Government pier 2 ft. above the then surface of the water in Lake Erie; the City Engineer gives the information that the surface of the lake is now about 2½ ft. lower on the average than at that time. Of course, this change of water level is foreign to the subject of this article, yet reference to it is of interest. Some cities use railroad data taken from the railroads passing through them. The city of Topeka, Kan., uses a datum established arbitrarily and perpetuated by ordinance, which is, unfortunately, so taken that it is above some of the lower portions of the city, and, therefore, in grade calculations it becomes necessary to use plus and minus quantities.

Sixth.—In concluding the description of the different monuments it may be added that it is surprising to find the number of cities that have no system of ranges at all, even such large ones as St. Louis, Mo.; Trenton, N. J.; Charleston, S. C.

Turning now to the choice of the best system of monuments, the writer would like to preface it with mention of the trouble encountered in his own town, where marble monuments from 18 ins. to 2 ft. long are used. As a result of the gradual changing of these stones the alignment and levels check badly, although in the beginning they were supposed to have been set with extreme care. When the frost is leaving the ground in the spring it is no uncommon thing to feel the stones yield under the foot if stepped upon, and the writer thinks there is a possibility at this season, when the stones have risen with the frost, that if a heavy rain should come, the water, by following down their sides,

might wash in the sand or earth under them and hence prevent their return to the original level. Whether there is really any such result following the rising of the stones in the spring he is not prepared to say, although as above mentioned the checking of the levels with what they are assumed to have been originally, is generally unsatisfactory. As far as the lines given by the stones are concerned, it is the writer's experience that in the spring and after heavy rains many of the stones are quite loose, and that a moderate blow will displace them laterally ½ or ¼ in., which new position they may thereafter retain.

After careful consideration the writer has formed the opinion that the two systems of monuments hereafter described are the best of their respective kinds, the advantages of one being offset by the smaller cost of the other.

(*a*) Marble stones set on 5-ft. range of either side line of streets, dressed 5 ins. square on top, and dressed down square for the upper 6 ins. of the stone; below this, roughly shaped out, flaring or tapering outwardly to a section 10 ins. square at the bottom, the whole stone to be not less than 3 ft. in length; hole drilled in top to mark the range line and upper surface (to be used as level bench) set just below the sidewalk, so that a loose brick or tile may be used to cover and protect it. A stone of this description, owing to its weight, depth below frost and the wedging effect of the earth upon its inclined sides, would be immovable and in every way fill the requirements of a perfect monument.

(*b*) Iron monuments set on 5-ft. range lines, a modification of the system used in Albany, N. Y., consisting each of a 4-ft. length of extra heavy, double-hubbed, tarred, cast-iron pipe, 4 ins. in diameter, with appropriately lettered brass cap leaded into the top, having a hole drilled in it to mark the range line; the monument to be so set that this cap, serving as a level bench, is just below the pavement and protected by a loose brick or tile.

Coming now to the expense side of the question, the iron monument has greatly the advantage, costing only $2 or $2 25 each, as compared with more than double these figures for the marble, even though in the latter the cheapest grade of stone be used (Sutherland Falls, $1 70 per cubic foot in Philadelphia). It may be added here that this Sutherland Falls marble is really better for range stones than the finer grades, for though it has not the whiteness and clearness of the cost-

lier stone, it has the more important advantages of much greater hardness and durability, besides being absolutely unaffected by frost. Of course this rule of the cheapest being best would not apply to granite monuments, as the cheaper grades of this stone are soft and liable to splinter.

On the whole the writer is hardly prepared to make a choice between the marble monument and the iron one applicable to all cases. In his judgment the former, looked at in the light of a monument only, is the better, having the advantages of weight, durability and the wedging effect of the earth, yet when it is considered that it will cost at least double as much as the cast-iron monument, it seems almost that the choice must be with the latter. The opinions of others on this subject would be very acceptable.

In conclusion, no matter what system of monuments is adopted, it should be the best of the kind obtainable. It is bad policy for any city to practice too much economy in the way of street monuments, and when the annoyance and occasional legal complication that is prevented by proper street marking is taken into account, no doubt remains of this; no stronger testimonial of the need for proper street marking can be found than the replies received from city engineers of cities unfortunately not so provided.

DISCUSSION.

HORACE ANDREWS, M. Am. Soc. C. E. (by letter).—Mr. Broomall has described the method of marking points of reference in various cities. It would appear that everywhere, except at Salem, Ore., the marks are merely surface ones. The most durable marks are those buried underground, such as are used for marking trigonometrical stations. In such cases surface marks should be used also.* In trigonometrical work, if either mark is omitted, it is apt to be the surface mark. Under such circumstances, I have found underground marks in excellent condition after 20 years; it is self-evident, however, that they may be very difficult to find.†

Where surface and underground marks are both used it is customary to place the latter vertically below the former. In this position the underground mark is so inaccesible, where the surface mark is a

* See U. S. C. S. Report for 1868, pp. 113-14-15. Report by Richard D. Cutts, Assistant.
† Science, Vol. I, pp. 269, 394, 458.

monument 3 or 4 ft. long, that, in city surveys, it would not often be referred to. To obviate this inconvenience, eccentric underground marks, in addition to the one at center, are very useful.*

I have recently had occasion to use a stone monument placed on the north boundary of the city of Albany in 1800, by Simeon De Witt. This stone is in an excellent state of preservation, but it is so much out of plumb that the center is very indefinite. In this case, the soil, which is of fine sand, has been blown from around the monument. Many other stone monuments in this city, set to mark the city line, are equally indefinite. While I recognize the fact that, from practical reasons, city monuments must be, in general, surface marks, it seems very desirable that important fundamental points should also have underground marks.

Some of the chief reasons for neglecting to mark reference points for city work are due to the time, labor and expense involved. The Albany monument, referred to by Mr. Broomall, is designed to reduce these objections to a minimum. It is light, weighing 50 lbs. only, for the 3-in. monument, showing a 4-in. brass cap on the surface. It can therefore be readily carried by one man or transported on street cars. It is strong and durable and can be conveniently set with a post-hole auger, with a light bar where necessary. The 3-in. monuments, with brass caps weighing 1 lb. 12 oz., purchased in a lot of 50, have cost $1 95 each. The 3-in., double-hubbed, 5-ft. soil pipe is generally the most suitable in size. Iron soil pipes can, however, be obtained of a great variety of sizes from almost any dealer in plumbers' supplies, so that size and cost can always be adapted to the requirements.

According to my experience, monuments to be stable should be set in holes of small diameter, dug, if possible, with a post-hole auger, otherwise with a crowbar, and the spoon shovel generally employed by telegraph linemen. If the soil is very loose, and the trouble and expense can be afforded, the stability of the monument may be much increased by filling around it with concrete. This plan was that finally adopted on the New York State Survey. If a long trench is dug, the monument is very liable to lean in the direction of the trench after a while. It is very inadvisable to attempt to set monuments with tools that are not suitable for digging a small, deep hole.

Malicious or mischievous interference is more to be feared than the natural disturbing action of the elements. I have seen the surface marks of a primary trigonometrical station nearly destroyed by fires, apparently made for that purpose; others I have seen battered to pieces with stones. The brass caps of the Albany monuments have occasionally been removed by means of fires built to melt the lead jointing, or by pounding them in. Such destruction is only to be feared in the suburbs, where the monuments may advantageously be

* New York State Survey Report for 1887, Appendix B.

buried, if their positions are suitably referenced. Surveyors in Albany have sometimes used pieces of old rails, 6 to 8 ft. long, with a cross marked on the end; these are admirably adapted to withstand hard usage, and are very suitable for newly laid-out streets.

I have found it difficult to adhere to rigid rules regarding location. In suburban places, where the houses are apt to be built back of the street lines, the street corner is the best and most convenient place for the monument. At other places the monument can be set near a corner, on one street line and 3 or 5 ft. from the other. In this position an instrument can be set directly over the monument, and can sight past the stoops of houses, which are tolerated in Albany where not projecting more than 8 ft. At too great a distance from the corner, sewers, gas and water pipes, when laid under the sidewalks, will be liable to disturb the monument. A location at the center lines of streets would seem to be in the greatest danger of disturbance.

The German practice in marking reference points is instructive. Sometimes the mark is a triangle cut on one vertical face of a monument.* Round monuments, moulded from cement, with lettering around the monument, have been used in Stuttgart, the monument having a spherical top to serve as a bench mark.† An example of some of the excellent referencing of trigonometrical points in Baden is given in "Das Deutsche Vermessungswesen," Vol. I, page 272. Pieces of agricultural tile are extensively used, and suitable "earth borers" are figured in German instrument catalogues. Sometimes a wide hole 1 ft. deep is dug, and the tile is set vertically in the bottom of the hole, by digging to an additional depth with the "earth borer." The bore of the tile is useful for receiving the sighting pole; a hole for this purpose being, indeed, generally made in the stone and iron monuments. After the completion of the survey, a stone monument of moderate size and cost is placed over the tile, the shallow hole then being filled up.

In detailed surveys of cities long built up, the problem consists in the accurate location of buildings which in themselves are monuments, and the only ones giving the street lines. In the very detailed survey of the city of Berlin, monuments are little used; crosses cut in the curb or sidewalks are of temporary service, and are so well and carefully measured from adjacent building corners that their location can be reproduced with precision. Attempts are frequently made, however, to mark the traverse points in old cities where the traffic is great and the possibility of disturbance is considerable. The best method of such marking that I have seen described is that devised by Mr. Gerke‡ for use in the city of Altenberg,§ a modification of that previ-

*Jordan, Vermess. Vol. I, p. 307. 1877.

†Zeitschrift fur Vermessungswesen. 1872.

‡Zeitschrift fur Vermess. 1871, p. 197, etc.

§Also employed by Mr. Nagel, in Leipsic.

ously used by him. Mr. Gerke summarizes the demands for the proper marking of points in the interior of cities as follows:

(1) Durable, solid material, not liable to danger from frost or decay.

(2) Secure placing and the selection of an easily found surface mark.

(3) The mark itself must not be buried and must be adapted for holding a sighting pole.

(4) A surrounding case must be used to guard against danger from repaving or disturbance. This case must be capable of lateral or vertical shifting without affecting the mark.

To answer the above requirements Mr. Gerke uses a cast-iron pin 60 cm. long, 8 cm. square on top, and 4 cm. square immediately above the point. The pin has a rounded top with a tapering hole about 3 cm. in diameter and 17 cm. deep, to receive the sighting pole. These pins weigh 14 kgr. and are driven into the paved streets with their tops 15 to 20 cm. below the surface. A small octagonal iron box, with lid held on by lugs and requiring to be turned with a key, is placed over the pin. The top of the box is flush with the pavement, which latter rests on a flange formed on the bottom of the box and thus holds it securely. The box weighs 16.5 kgr. Box and pin together cost about $1 10, which Mr. Gerke justly remarks is extremely cheap. The tops of Mr. Gerke's iron pins are designed to serve as subordinate bench marks. For bench marks of importance there are round-headed bolts cemented into holes drilled into the walls of houses in many German cities. The initial bench mark of Prussian surveys is of enameled glass inlaid in a block of granite in the wall of the Royal Observatory at Berlin. It has a millimeter division, running 10 cm. each way from the central mark, which latter is 37 m. above the normal zero. This scale is protected by a metal box with a locked door, the whole arrangement being quite ornamental in appearance. An agate topped bolt in the foundations of another part of the building gives a means of guarding against possible loss of the enameled scale.

For absolute security, an initial datum plane might well be referred to not less than three bench marks, such as are described by Mr. George W. Cooley, in the *Transactions* of the American Society of Civil Engineers for 1889. I am of the opinion that such bench marks would be preferable to marks made on the walls of buildings under most conditions, and with foundations that are heavily loaded. Mr. Cooley's bench marks are beyond the influence of frost; they cannot settle into the ground from insecure foundations, as many buildings are known to, and they would not seem to be liable to disturbance from earthworms, a danger indicated by Darwin.

C. M. Broomall, Jun. Am. Soc. C. E.—The description given by Mr. Andrews of the cement monument used in Stuttgart is very

interesting, and such a monument, if its durability could be insured, ought to be a good one. It would seem to the writer, however, that there would be danger of its going to pieces. This might be prevented if the cap could be so made as to cover and enclose the upper 6 or 8 ins. of the monument, being held by iron rods, or other means, to the mass of cement below. For the fullest application of this monument it would be necessary to have it so that it could be made *in situ*, the hole being dug of proper size and filled with cement and the cap then attached and centered before the cement had hardened. The details of this attachment would have to be such as to make it firm and lasting.

In regard to the buildings becoming monuments in the built-up portions of cities, this is true to a certain extent; but when it comes to making use of them for the protection of streets into unmarked territory they would seem to be of questionable use unless cumbersome and detail notes were preserved of the exact location of some properly defined point on each "range" house. Unless these defined points were regularly prepared and marked in the wall of each house, and on some definite system of lines, a great loss of simplicity would result, making lengthy extracts from the city plan necessary for every piece of work.

The use of several initial level benches is to be recommended. If this is not done it might result in the state of things existing in the writer's town, where the datum stone, the basis of all levels, originally situate in an adjacent valley, has become washed away. As the local range stones have been more or less subject to natural changes as time passed, the consequence is that when any extensive leveling operations are undertaken it is necessary to do an amount of averaging up that is anything but satisfactory.

It is much to be regretted that the question of street monuments is not separable from the money side of the matter. The kind and extent of monuments is not only dependent upon mechanical principles, but is almost equally dependent upon the amount of money the authorities are willing to expend, which is not large. Since the stones are lost from time to time and the engineer is not, as a rule, authorized to replace them, there is developed a strong tendency toward decline, which is seldom successfully resisted. It is only when things have gone so far that something must be done that the city authorities see the false economy of their action.

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THE LOAD LINE IN TELEPHONE EXCHANGES.

By A. V. ABBOTT, Jun. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

A study of the variations in loading to which dynamic plants are subjected forms one of the most interesting of engineering investigations. The station loads carried by electric and cable railway plants have, during the past few years, formed a prolific topic of scientific discussion, and the results have revolutionized certain departments in steam engineering. Similarly, the managers of electric light plants are perpetually seeking to realize a maximum output with a minimum of invested capital and operating expense.

Among interesting load lines, those presented by the daily burden on telephone exchanges exhibit some features of peculiar interest, well worthy of professional consideration. The telephone exchange is merely the mechanism whereby different parties may be rapidly and reliably placed in talking relations with each other, and the exchange only fulfills its office in proportion to the efficiency with which this

end is accomplished. Considering that some of the larger exchanges in this country are handling messages at the rate of 100 000 000 a year, the importance of a consideration of the exchange load line becomes apparent.

Before passing to the actual examination of the load line proper, it will be pertinent to look at the principal and essential features of the exchange system, in order that the relation of the load line to the apparatus and methods of operating may be fully appreciated.

A telephone exchange consists of one or more offices, in which the switching apparatus for placing subscribers into intercommunication is located. The simplest exchange consists of a single office into which the lines from all subscribers converge. Such an office is always the commencement of any telephone exchange, and is, naturally, located as near as possible to the electrical center of gravity of the subscribers' district. As business increases and additional subscribers are connected with the exchange the territory served enlarges, and a point is soon reached when the line mileage from the varying subscribers to the central office becomes an important consideration.

As in any exchange the actual number of subscribers in conversation at any one instant is comparatively a small proportion of the entire number served, territorial dimensions soon indicate the advisability of establishing a branch office, into which the more distant subscribers may be carried, the switchboard of which shall be connected with the original central office by means of a small number of trunk cables that are sufficient to serve the maximum number of subscribers that are likely to be in conversation at any single instant. Thus, in the largest cities, the growth of the exchange is centrifugal, extending outward from the original central district. The telephone system has been very aptly compared to the nervous system of a sentient organism, in which the various outlying offices may be represented by the subordinate nervous ganglia—the main, or central, office occupying the place of the brain.

At each of the offices in an exchange, the appropriate apparatus for rapidly switching subscribers into talking relations must be located. This apparatus usually takes the form of a switchboard—a typical representation of which is indicated in Plate X.

Considering this, it is evident that the switchboard consists of vertical panels carrying the subscribers' switches, or spring-jacks

underneath which a shelf is located having a number of flexible cords terminating in metal plugs, the insertion of which into the spring-jacks of two respective subscribers places them in talking relations with each other. Directly beneath the cord shelf, manual keys are located, enabling the operator to place herself in communication with the various subscribers, and beneath the keys are located annunciators serving to notify the operator that a connection is desired.

The manipulation of the switchboard will be more clearly understood by reference to some of the electrical features, as contained in the circuit common to the so-called standard switchboard, shown in Fig. 1.

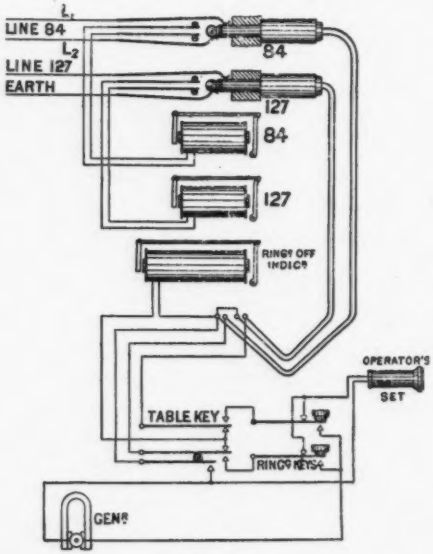

FIG. 1.

The diagram illustrates two subscribers, Nos. 127 and 84, in conversation. Imagining for a moment that the plugs introduced into Nos. 84 and 127 are withdrawn, it will be seen that one side of the line of each subscriber enters the spring-jack at the exchange, and, passing through the jack, runs to an annunciator bearing the appropriate subscriber's number. The other side of the line leaves the annunciator through

PLATE X.
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the spring-jack, and returns to the subscriber. The electrical impulse produced by turning the crank of the subscriber's magneto passes through the spring-jack, thence to the annunciator, allowing the shutter to fall and disclosing the appropriate number. Upon noticing the falling annunciator shutter, the operator lifts one of the plugs attached to the flexible cords in front of her, and places it in the spring-jack bearing the number corresponding to that disclosed by the annunciator. At the same time she presses the table key, thus connecting her telephone with the subscriber's line. Examining the diagram in Fig. 1, it will be seen that the introduction of the plug in the spring-jack lifts the springs of the jack in such a manner as to disconnect the annunciator and, at the same time, connect the operator's talking set from the table key with the subscriber's line. When the order is received, the operator lifts the companion plug of the one first inserted, placing it in the spring-jack of the subscriber with whom conversation is desired; simultaneously, she presses the ringing key, thus sending an impulse through the line of the called subscriber, causing his magneto to sound. As soon as the called subscriber answers, the operator releases the table keys, thus cutting her telephone out of circuit and placing the two subscribers in private talking relations. In the diagram, it will also be noticed that a ring-off indicator, or "clearing-out drop," as it is usually called, is placed as a shunt across the pair of cords connecting the two subscribers. As this indicator is wound to have a large impedance, it but very slightly shunts the rapidly alternating telephonic waves, but is readily sensitive to the slower alternations of the magneto current. Thus, at the close of conversation, a turn or two of the subscriber's magneto is sufficient to throw the clearing-out drop, indicating to the operator that conversation is terminated and advising her of the necessity of the withdrawal of the cords and plugs. A circuit of this kind is in use only in the smaller exchanges, where each subscriber's line is supplied only with a single spring-jack and is readily in sight of the operators; the mere presence of the plug in the spring-jack serving to indicate that the line is engaged and debarring the operator from interrupting a conversation already in progress by the attempt to connect either of the talking subscribers with any other party that may desire connection with them.

Experience has shown that a single operator can rarely attend to

more than 100 subscribers, and in the more busy exchanges from 50 to 60 is usually all that can be adequately served. Thus, in large exchanges the proportions of the switchboard would soon place a large number of the subscribers out of sight and out of reach of many of the operators working a switchboard constructed upon the lines indicated. It is, then, customary to have recourse to the multiple switchboard, in which the line of each subscriber, instead of being extended to a single spring-jack, is placed in series through a number of jacks so arranged that each operator has access to a jack connected to the line of every subscriber. The outline of such a circuit is indicated in Fig. 2, showing the location of a number of

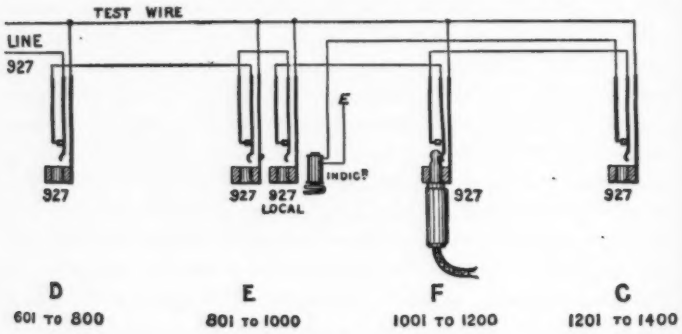


FIG. 2.

operators—*D*, *E*, *F* and *G*—in front of each of which a single line is multipled by passing through an equal number of spring-jacks set in series with each other. By such an arrangement, it is evident that any operator may readily reach all of the subscribers in the exchange. This method, however, requires additional apparatus in the circuit, to provide the operator with a means of ascertaining whether a line is engaged or not. This is accomplished by means of the "busy test" method, which consists in providing a local battery in every cord circuit. This cord circuit is shown in Fig. 3. Here it will be noticed that the sleeve of the plug is connected to the earth through a resistance coil and a small battery. When the plug is inserted in the spring-jack (see Fig. 2) the battery is placed in electrical contact with the jack ring. It will also be seen that the center of the operator's telephone is connected to ground, and the operators are instructed to touch, with

the tip of the plug, the ring of the subscriber's jack with which connection is desired. By tracing the circuits, it is apparent that the insertion of the plug places battery upon the rings of all the jacks on each line which is engaged in talking, and, by touching any ring with the tip of the plug, the operator, if the line is engaged, will hear a sharp click in her telephone, thus notifying her of the fact that the line in question is under conversation.

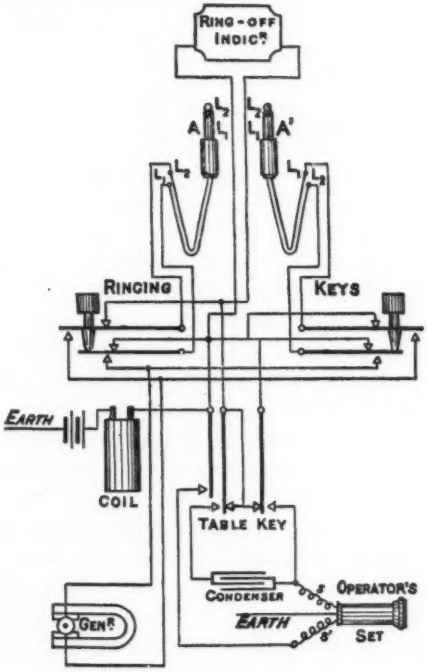


FIG. 3.

The shape of the load line in any exchange is evidently governed partly by the speed and facility with which the operators are enabled to perform the various evolutions described as necessary to make connections between subscribers, and partly by the nature of the business done by the exchange. The work done by the operator thus becomes an important governing factor in the load line.

Fig. 4 is a diagram representing the time occupied by the operator in performing the various functions necessary to complete a connection. These results are derived from investigations made upon the Cortlandt Street office of the New York exchange.

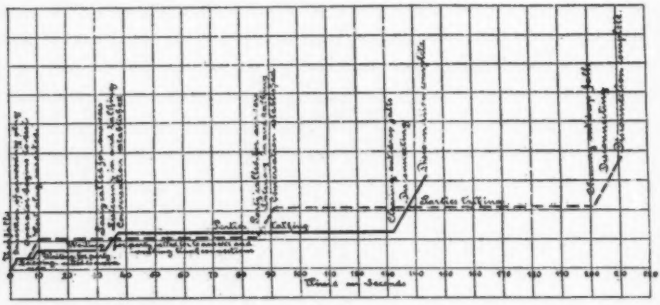
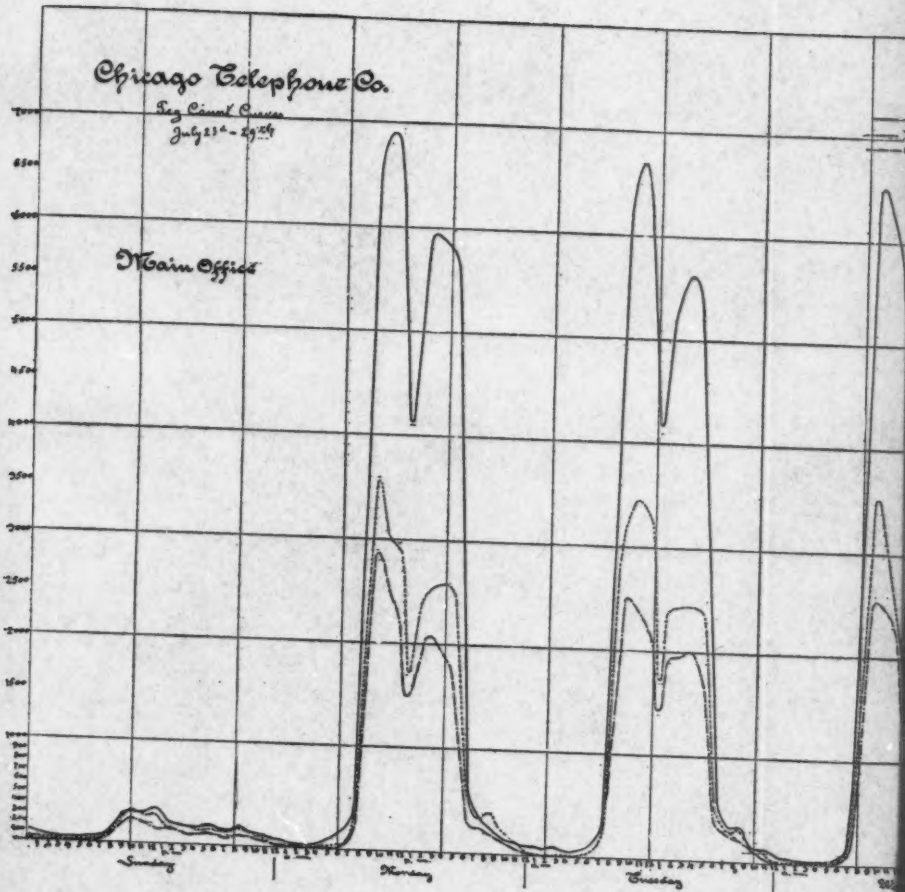


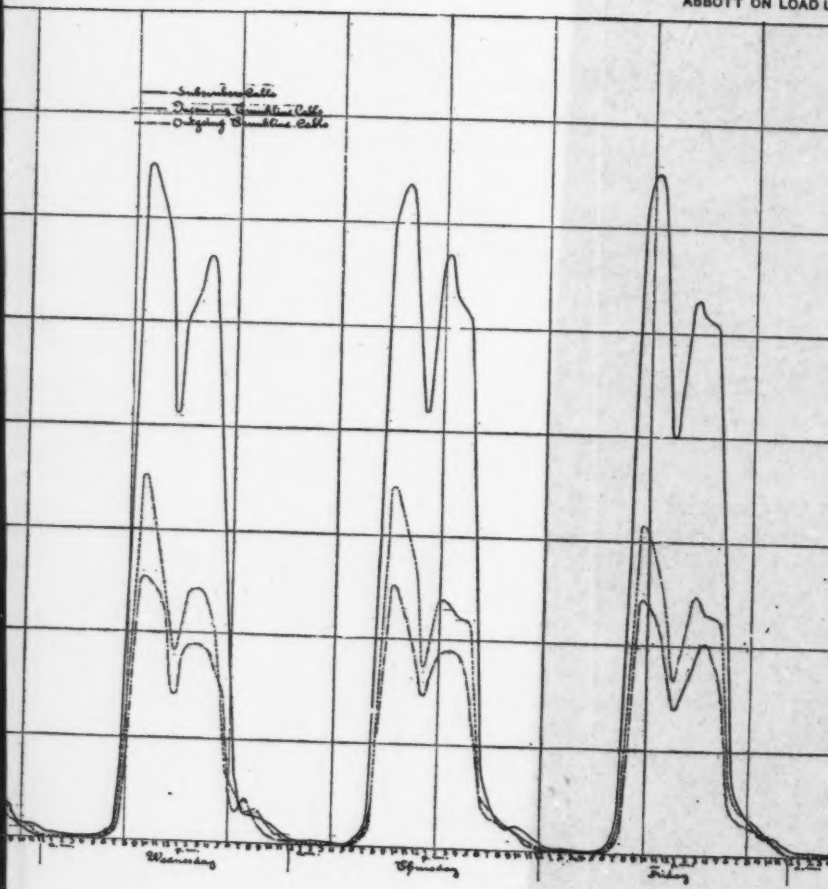
FIG. 4.

The axis of X in the diagram is taken to represent intervals of time. The fall of the drop is assumed at zero time. A little over two seconds are occupied by the operator in inserting the answering plug. Six seconds are consumed in obtaining the subscriber's order and in testing the desired line to ascertain whether it is engaged or not. About 23 seconds are exhausted in obtaining an answer from the called subscriber, while about five seconds more are expended in seeing that the connection between the two subscribers is fully completed, and that conversation has been initiated.

About 97 seconds seems to be the average of most conversations and about 10 seconds more suffice to receive the clearing-out signal and disconnect the parties, leaving the lines ready for another call. Such is, diagrammatically, the history of the operations and time expended in completing the average local conversation between two subscribers extending into a single office.

The business of the exchange is still further complicated by the frequent necessity of trunking calls between outlying offices, for, as already indicated, the growth of the exchange soon leads to the establishment of a number of branch offices connected between themselves and to the original center by means of trunk cables. When a message proceeds through two offices, it must of necessity pass through the hands of two operators and through two switchboards. To accomplish


Chicago Telephone Co.
Main Office
Monday
Tuesday


Wednesday
Thursday
Friday

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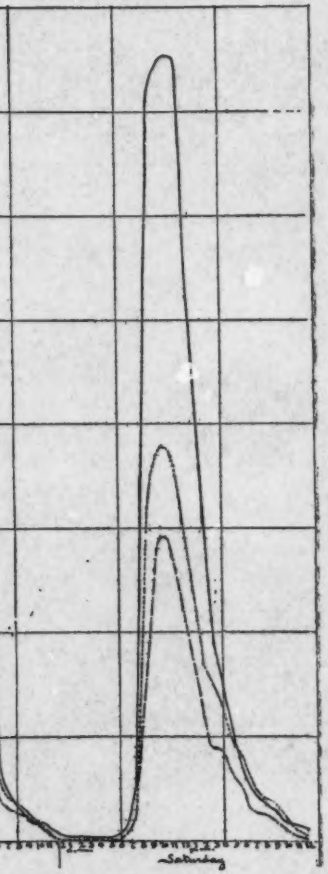


the business thus transferred, it is customary to locate in front of every operator a certain number of trunk lines extending to all the other offices in the exchange. At the receiving end the trunks from the through offices are brought to special sections of the switchboard devoted to trunking business alone. In the trunking sections no subscriber's drops are placed, the attention of the incoming trunk operators being devoted entirely to receiving connections over the trunk lines and completing them on the multiple located in front of them. In Fig. 4 the dotted line illustrates the time consumed in calls which are trunked between offices. Thus, starting from the origin, a little little longer time is consumed in inserting the test plug, for the reason that the operation of testing trunk lines is rather slower than that occupied in subscriber's lines, as it usually happens that several of the trunks are engaged and a number of lines have to be tested in order to find one which is free.

In the local connection the party called for answers in about 33 seconds, while in the trunk connection some 85 seconds are consumed in passing through the second office and in obtaining an answer from the party called for. For this curve, also, it would appear that trunk conversations last a little longer than ordinary local calls. The operation of disconnecting, however, seems to be performed with equal rapidity.

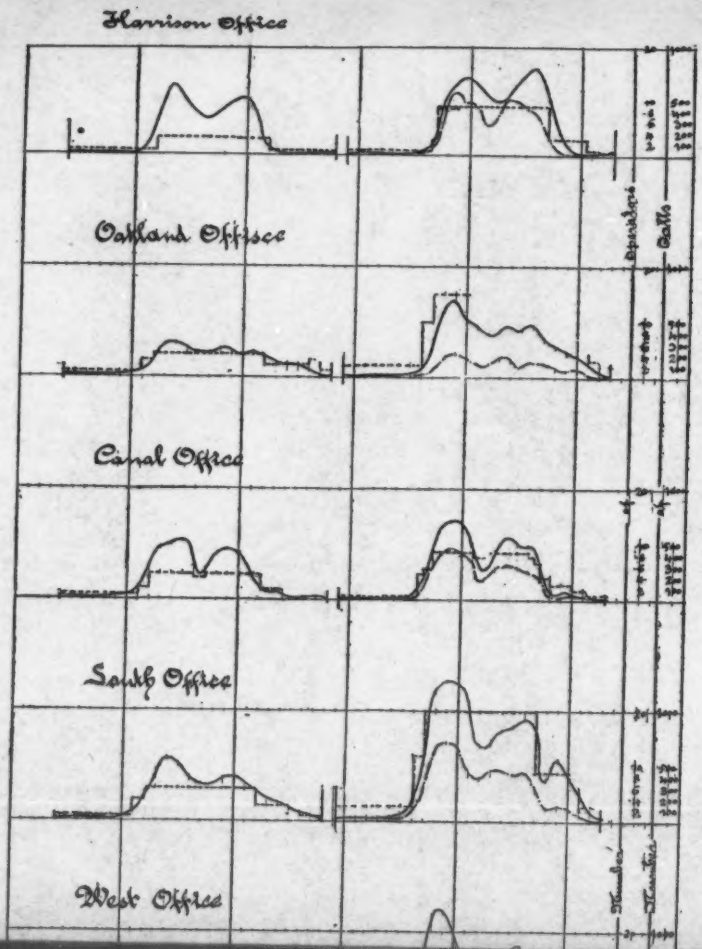
To determine the load line, it is now customary in nearly all the larger American exchanges to make frequent tests of the amount of business. To this end, recourse is had to what is termed "operator's peg count." In front of each operator is placed a panel containing the subscribers' spring-jacks, each one bearing an appropriate number. The operator is supplied with a wooden peg, which at the commencement of the count she inserts in jack 0. As fast as calls are received she moves the wooden peg from hole to hole, counting calls something after the fashion of a cribbage board. At the end of each hour, the superintendents in the operating-room note the position of the peg, thus determining the number of calls which have been received by the individual operators. At the end of the day, the sheets bearing the facts thus obtained are tabulated and the results plotted in a convenient form for inspection.

Plate XI is a chart of the business transacted in a week by the main office of the Chicago Telephone Company. At the time this count

was made, this office embraced about 5 000 subscribers, while the entire exchange numbered some 10 offices, including about 10 000 subscribers.

In the diagram, the vertical axis indicates the number of calls made, while the horizontal axis is divided into hours throughout the whole week. The diagram commences at midnight on Sunday and extends to midnight on the succeeding Saturday. The full lines in the diagram indicate the subscribers' calls which are made and completed in the office under consideration. The fine dotted line indicates the incoming trunk line calls, namely, those calls which originate in subscribers located in external offices, and which are trunked into the main office, while the broken dotted line indicates the outgoing trunk calls, that is to say, those calls which are received by subscribers in the main office and which are not completed there, but are trunked to subscribers located in some of the outlying offices. From midnight to 7 o'clock on Sunday morning, little business was done by the exchange, the number of calls in any one hour barely reaching 100. From 7 to 10, the business steadily increased, reaching at 10 o'clock a maximum of about 350 calls per hour. Another maximum occurs between 12 and 1, reaching about 375 calls. From this point the business steadily decreases, reaching a minimum between 2 and 3 on Monday morning. From 3 o'clock to about 7, there is a slight increase. At 7 o'clock the business of the day begins, the number of calls rising rapidly from 200 per hour at 7 o'clock to a maximum of 6 920 calls an hour at about 10.15. From 10.15 to 12.30, the business decreases, being reduced to 4 150 calls per hour during lunch time. From 12.30 to 2.15, the business again increases, reaching a second maximum of 5 950 calls. From this point a rapid decrease is observed, to the rate of about 500 calls an hour between 7 and 8 o'clock in the evening. The curve at this point turns and slowly decreases again until about midnight.

Between 2 and 3 o'clock, a slight increase is observed, due to newspaper business, while the minimum of the entire 24 hours is reached at 4 A.M., at a rate of about 50 calls an hour. Comparing the business of the successive days in the week, it will be observed that rather more business is done on Monday than any of the succeeding days, with the exception of Saturday. During Tuesday, Wednesday and Thursday, the business decreases, reaching a minimum on Thursday. On Friday,


Harrison Office
Oakland Office
Canal Office
South Office
West Office

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V
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PLATE XII.
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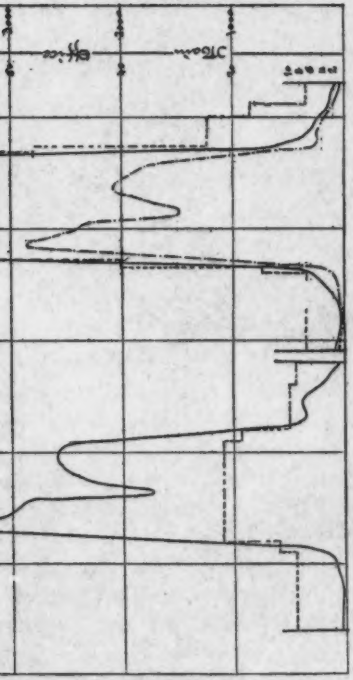

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a slight increase is observed, while on Saturday the effect of the summer half holiday is plainly marked. Here, it is evident that an effort has been made to transact the entire business of the day in the forenoon, the maximum being reached at 11 A.M., with a rate of about 7 650 calls an hour. From 11 A.M., the business drops sharply, there being no indication of any noon hour, but the holiday effect is also noticeable in the increased number of calls which are made during the evening hours, from 6 to 9 o'clock. While the chart thus given may be considered a typical representation of a week's business, it is necessary to take carefully into account the modifying effects of the general state of business in the city, the effect of any unusual occurrence, such as holidays, large fires, railway accidents, or other contingencies, and, particularly, the state of the weather. Thus, during the summer time, especially in the midsummer months, the business of the exchange is liable to fall off, owing to general slackness from vacation time, and also due to fine weather making pedestrianism attractive. Conversely, in the winter time, when business is more brisk, or when stormy weather is conducive to office confinement, the business of the exchange may rise enormously.

A study of the load line, however, is more particularly advantageous in adjusting the operating force to the business of the exchange in a way to make the quantity and quality of the service a maximum with a minimum of operating expense.

In Plate XII some curves are given of the main office in the Chicago exchange, together with five of the outlying offices. These curves were plotted from results obtained in July, 1893. The arrangement of the curve is a little different from that of the preceding diagram, that is to say, connections which originate and are completed in the same office are plotted in full in heavy line on the right-hand side of the diagram, while the incoming trunk calls are indicated in a similar manner by a heavy line on the left-hand side of the diagram. In the diagram on the right, out-going trunk calls are indicated by the broken dotted line, while on both curves the number of operators required to transact the business given by the full curve is indicated by the fine dotted line. There seems hardly to be such a parallelism between these two lines as the most efficient service would indicate. However, in adjusting the number of operators to the business transacted, it must be recollected that it is impossible to decrease

the operating force precisely in accordance with the service demands. The operator is necessarily a unit, and one of considerable magnitude, particularly when considered in proportion to a single call. Thus, to serve half a dozen subscribers will require one operator, while 100 could be served with equal facility. As it is impossible to subdivide the individual operator in proportion to the business to be transacted, there occurs a great discrepancy between the force line and the load line in certain parts of the diagram.

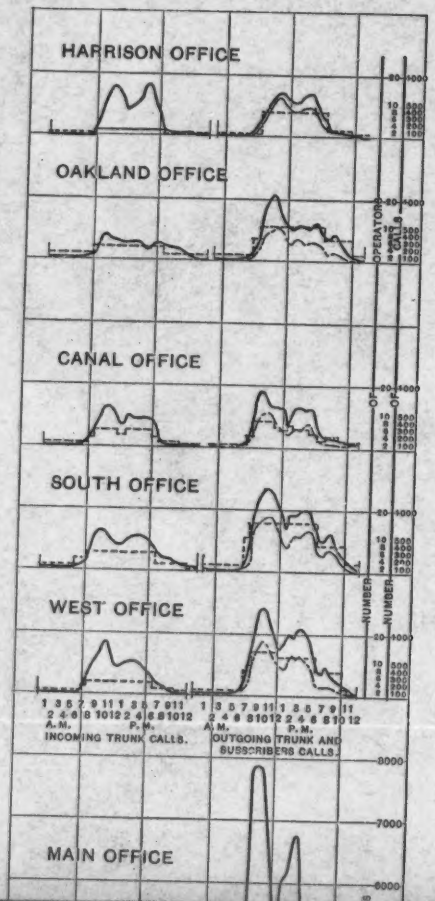
At night time, for example, the number of operators rises far above the actual force which could transact the business. It is essential to watch the entire switchboard, as an occasional call may come in upon any section, and, as the switchboard in the office under consideration is nearly 200 ft. in length, quite a large operating force is required, simply for supervision, irrespective of the number of calls to be answered. It is also impracticable to change the working hours of the force in a manner to coincide exactly with the variations in the business. While this can be done to some extent, it will cause only a partial agreement between the force line and load line. As an example, however, of what has been done in this direction, as developed by a study of exchange load lines, refer to Plate XIII.

In Plate XIII 6 900 calls were handled with 82 operators.

In Plate XIII 8 450 calls were handled with a maximum force at any time of 72 operators, while the whole force line indicates a number in closer agreement with the load line.

A similar change may be seen, by comparing the load and force diagrams of the Harrison office, Oakland office, South office and West office Taking the whole exchange in the time intervening between the two peg counts, which are here charted, the business increased about 8%, upwards of 1 000 000 additional messages a month, while the operating force was decreased some 18%, with marked improvement in the quality of the service attained.

It is also curious to note the effect on the load line of the kind of district in which the exchange is located. Thus, in the load line for Harrison office, it will be noticed that almost no business is done after 8 o'clock P. M., while in South office, between 7 and 8 P. M., a maximum occurs of nearly 600 calls an hour. This is explainable when it is considered that the Harrison office is located in a district which is exclusively a large business district, the offices of which uniformly close


HARRISON OFFICE
OAKLAND OFFICE
CANAL OFFICE
SOUTH OFFICE
WEST OFFICE
MAIN OFFICE
OPERATORS
NUMBER OF CALLS
1 3 5 7 9 11 1 3 5 7 9 11
2 4 6 8 10 12 2 4 6 8 10 12
A.M. P.M.
INCOMING TRUNK CALLS.
A.M. P.M.
OUTGOING TRUNK AND SUBSCRIBERS CALLS.

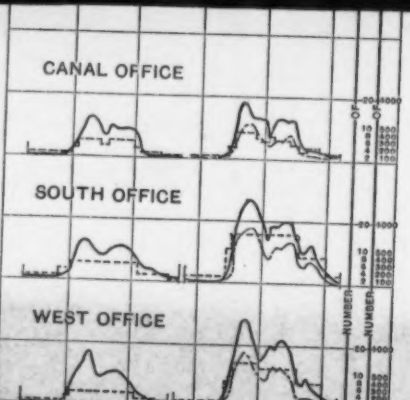

CANAL OFFICE
SOUTH OFFICE
WEST OFFICE
NUMBER OF
NUMBER OF

PLATE XIII.
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between 5 and 6 P. M., while in the case of South office, the district is to a great extent a residence one, and the maximum indicated between 7 and 8 o'clock is caused by the formation of evening appointments.

In a like manner the study of such load lines forms an exceedingly valuable source of information in the location of branch exchanges and the distribution of subscribers' lines. The trunking of calls between branch offices has already been alluded to. It is quite evident that the establishment of branch exchanges increases the cost of operating, as it requires the expense of additional buildings, additional supervision and a general increase in the non-productive portion of operating expenses. Where, by means of a branch exchange the capital invested in the subscribers' lines may be decreased by shortening those lines, resulting in such a saving as to warrant the increase in operating expenses, a branch exchange becomes profitable. On the contrary, if the business in the district covered by the branch exchange is of such a nature as must necessarily come to the main office, the establishment of a branch exchange must be supplemented by such a large number of trunk lines as practically to extend the line of each subscriber into the main office. Thus, under such circumstances, the establishment of a branch exchange becomes an impediment rather than an assistance, as the speed of the service is reduced, greater expense is incurred, and no particular saving can be made in the capital expended. For example, in the Harrison office, in both of the diagrams here given, it will be seen that the outgoing trunk calls amount to a very large proportion of the entire business of the office; actually in some cases, instances rising to from 85 to 95% of the entire business of the office. A careful analysis of the business done by the Harrison office indicates that such a large proportion of the work was trunked through to the main office as to make the establishment of the Harrison office, viewed simply from the standpoint of operating expense, not fully justified. By a careful re-arrangement of the subscribers in the Harrison office, this proportion of trunking has been very largely modified, so that at the present time not over 60 to 70% of the business done by the Harrison office is trunked out of it. As a comparison, refer to the curves of the main office, in which it is seen that of the total business originating in the main office, only about 30% is trunked out of it.

Such are some of the more salient deductions to be drawn from a

study of telephonic load lines. The improvement in service which has resulted to the Chicago company during the past six months from investigations of this description, has been so marked that a regular system of peg counting now forms one of the features of the operative service of the company, regular counts being made on the tenth of each month. A special count takes place whenever circumstances of so peculiar a nature arise as to seem worthy of investigation.

Exchanges in New York and Boston are following a similar course, deriving like advantages from the information thus obtained, and by means of an interchange of curves between the different exchanges the amount of valuable information obtained is largely augmented.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

722.

(Vol. XXXII.—July, 1894.)

NOTES UPON TESTING BUILDING STONES.

By F. LYNWOOD GARRISON, Assoc. M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

Probably no one who has given the subject of testing building stones careful consideration is willing to admit that the methods now in vogue for determining the strength of structural material of this character are satisfactory or entirely reliable. This condition is probably due, as an eminent authority remarks, "to a lack of knowledge of the methods by which such tests can be made, and to a lack of appreciation of the necessity of such tests." * The old idea that one stone is as good as another as regards durability and strength cannot be too strongly condemned, since all stones or rocks are compound bodies, often exceedingly complex, composed of aggregations of various mineral substances whose individual nature and their respective influence upon one another should be understood as far as is possible, to arrive at a proper appreciation of the whole. This necessitates at least an elementary knowledge of mineralogy, geology and lithology, the study of which has unfortunately not been included in the training of most civil engineers and architects.

* Merrill. "Stones for Building and Decoration," p. 384.

In this connection the writer cannot do better than to quote the words of Dr. Alexis A. Julien in Vol. X of the Tenth Census of the United States.* "Hardly any department of technical science is so much neglected as that which embraces the study of the nature of stone, and all the varied resources of lithology in chemical, microscopical and physical methods of investigation, wonderfully developed within the last quarter century, have never yet been properly applied to the selection and protection of stone for building purposes." Although this was written a number of years ago, it is extremely doubtful if much improvement or progress has been made since, and engineers in general probably know little, if anything, more of the properties and peculiarities of the wonderful varieties of structural material so bountifully provided by Nature.

In presenting these notes for publication it is not the writer's desire to set up any system of testing building stone or to present any new scheme of his own, for, with possibly one exception, none of the methods or tests mentioned herein are in the least degree new or original. The sole aim of this paper is to emphasize the necessity and desirability of using, developing and improving the systems already established. A few years ago when attention was called to the utility of the microscope in the metallurgical investigations of iron and steel, many competent metallurgists doubted its practical value ; now, however, metallurgical literature teems with valuable papers upon the subject, and the practical value of the microscope in this branch of technical science has been fully established.

In the writer's opinion the practical value of microscopical examination of stone is much greater than that of ordinary metallurgical productions. In the one case we have a natural production about which we can know nothing without an investigation. In the other case we have an artificial material made for a distinct and definite purpose, to effect which we must needs know more or less of the characteristics and relative reactions of the individual elements constituting the desired compound.

The tests ordinarily applied to building stone, to determine its physical properties, although few in number, are in some instances rather complicated and often unreliable. The first and most essential is to determine the structure and character of a stone, to know whether it

* "Report on the Quarry Industry," p. 364.

be a granite, syenite, sandstone, quartzite or something else. Although an expert can usually determine at a glance to which, if any, of these groups a particular stone belongs, it is frequently possible to determine the precise lithological character only by a microscopical examination. Thus, for instance, there is a class of Cambrian rocks commonly called sandstones (Potsdam ?) that are not sandstones at all, but are hard, compact rocks known as quartzites, which have been derived from sandstones by metamorphic action. The essential difference between a sandstone and a quartzite lies in the presence of secondary silica between the quartz granules comprising the latter; the presence of this secondary silica or quartz can be determined for a certainty only by microscopical means. The microscope is not only useful in determining the structure of a stone, but it has an even greater practical value in making it possible to detect the presence of deleterious substances such as pyrite, and marcasite (iron sulphides) or other minerals whose chemical composition is affected by atmospheric agencies and thus exert a deleterious effect upon the stone. The application of the microscope to this, as to every other purpose, requires some skill and training, which may, however, be readily acquired by anyone to whom the subject is of sufficient interest, microlithology being thoroughly treated in standard works available to all.

Strength.—The character of a stone being established, it is usually desirable to determine its strength as a resistant to crushing, shearing and bending strains. Ordinarily the first is considered sufficient, but the determination of the second and at times the third is often more essential.

Form of Specimens.—In determining the compression strength of a stone, cubical specimens are usually prepared varying in size from 1 in. to 5 ins.; the dimensions of the cubes are important factors, since it has been found that the resistance increases in the ratio of the cube roots of the sides of the respective cubes expressed in inches.* More generally and with greater simplicity this law may be expressed thus: The strength of geometrically similar test pieces varies as the square of homologous sides.† Consequently a stone will develop its maximum resistance in the largest cubes.

* Gillmore. "Notes on the Compressive Resistance of Freestone, Cements, etc.," pp. 20-29.

† Unwin. "The Testing of Materials of Construction," p. 422. London, 1888.

Too much trouble cannot be taken in preparing the test cubes, the care with which it is done having a most important influence upon the result. When such small samples are dressed by hammer and chisel, they become filled to some extent with minute cracks, the number of which increases inversely with the size of the cube. If, however, the cube has been carefully sawn and ground down to the requisite dimensions, this weakness is avoided, or at least reduced to a minimum.

Cushions.—The faces of the cube, which come in contact with the compression plates of the testing machine, should be perfectly smooth and even, otherwise they must be provided with cushions of plaster of paris or some other material, which will avoid the superficial irregularities and produce a uniform bearing upon the compression plates. Baker states that "the nature of the material in contact with the stone while under pressure is a matter of great moment. If the materials which press upon the top and bottom of the specimens are soft and yielding and press out sideways, they introduce horizontal forces, which materially diminish the apparent crushing strength of the stone. If the pressing surfaces are hard and unyielding, the resistance of these surfaces adds considerable to the apparent strength." *

While these remarks would seem to lay undue stress upon a comparatively unimportant detail, it is, however, necessary in all cases to provide a uniform bearing between the compression plates and the specimen. Whenever possible, this bearing should be directly upon the specimen itself. The faces of the cube must, therefore, be perfectly smooth and parallel, and, when such is the case, irregularities in the results cannot be attributed to an imperfect artificial bed or bearing.

Bed or Natural Position.—Care should always be taken to determine whether the pressure is applied upon the bed of the stone or upon its edge, since a stone will always develop a maximum strength when the pressure is applied in a line perpendicular to its natural position or "grain." It is not always possible to determine the bedding of a rock from a mere inspection of a number of samples. Indeed, even at the quarry, in some instances, it may puzzle an experienced geologist to determine the original or natural horizontal bed of the rock if it be of a sedimentary origin, or a metamorphic rock, and when eruptive it may be quite impossible, although most, if not all, eruptive

* "Treatise on Masonry Construction." I. O. Baker, p. 6.

rocks have a tendency to break in certain directions or planes in which the cohesive power of the stone is weakest. This property may be considered as similar to the cleavage phenomenon of crystallized minerals, and for practical purposes when testing a stone these planes may be considered as the bed. This cleavage property can usually be detected in massive rocks, such as some of the granites, by experienced quarrymen.

In many metamorphic rocks the bedding is made very distinct by the distribution of the mica in such a manner that its laminæ are arranged in definite parallel planes, which impart a stratified appearance to the rock. When this stratification becomes marked, the stone is known as gneiss ("stratified granite"). With sandstones, and probably also with quartzites, the proper recognition of the bed or grain has another point of practical value, since such stone will not only weather better when laid upon its natural bed, because all sandstones most readily absorb moisture in the direction of their grain or bed, but it will withstand a greater amount of heat without disintegrating. This is an important fact in cities, where walls are apt to become highly heated in fires.

FIG. 1.

FIG. 2.

It is desirable that the pressure applied by the testing machine shall continue until the specimen is completely crushed into smaller pieces. The character of these fragments should be noted, as it has been observed that in the stronger stones there is a tendency, when the pressure is applied upon the bed, for these pieces to develop into pyramidal shapes with round edges (Fig. 1); whereas, in weaker samples

of probably the same stone, or if the pressure has been applied on the edge, for the fragments to assume an angular flaky character (Fig. 2).

Some stones will not assume either of these forms, but will crush or crumble into numerous small fragments of no particular shape.

Shearing Strength.—One of the most useful tests to which a stone can be subjected is that to determine its resistance to shearing strains. It is, moreover, a test seldom made, and a description of the method recently adopted by the writer may be of interest. It was required to determine the suitability of certain stone for street paving purposes, and while the determination of the stone's crushing strength was very useful, its resistance to shearing strains was deemed a factor of more practical value.

At the suggestion of Mr. Tinius Olsen, of Philadelphia, the well-known builder of testing machines, the writer had the stone test pieces made into rectangular blocks or slabs 1 in. in thickness, 2 ins. in breadth and 4 ins. in length. In making the tests, each stone block was securely clamped between two heavy cast-iron plates made especially for the purpose. The center of each of these plates was provided with a rectangular slot 1 in. wide by 2½ ins. long, whose sides had been carefully machined and were perfectly smooth. The stone test piece was placed so as to cover the slot in each of the plates, which were then clamped together and the specimen held in place by two screw bolts passing through the iron plates. In this way both ends of the specimen were supported; then, by inserting a steel block or punch into the slot of the upper plate and applying the pressure, it was possible to shear or punch out a section of the specimen 2 x 1 x 1 ins., thus subjecting the stone to no other than a shearing strain.

The results of four tests made in this way upon hard quartzite blocks are given in the following table:

	Size, width and thickness.	Area. Square inches.	Broke at. Pounds.	Strain per square inch. Pounds.
No. 1.....	2.027 1.020	2.067 x 2 = 4.134	28 930	6 990
No. 2.....	2.032 .994	2.019 x 2 = 4.038	9 600	2 370
No. 3.....	1.990 1.038	2.063 x 2 = 4.130	22 980	5 560
No. 4.....	1.990 .930	1.850 x 2 = 3.700	23 550	6 360

A number of tests made upon cubes of the same material is given in the next table. In this case the shearing tests were made by clamping one-half of the block between the bearing blocks of the machine and then applying the load to the upper face of the projecting half, the bottom being unsupported, until it was shorn off.

A bending strain is undoubtedly introduced in this case, and the results were by no means satisfactory, as a comparison of the tables will show; in the former case they were from two to five times higher.

SHEARING TESTS OF 2-IN. QUARTZITE CUBES.

No. of specimen.	Size.	Total shear in pounds for entire section of 4 sq. ins.	Shear per square inch, in pounds.	
7 871.....	2 x 2 ins. = 4 sq. ins.	7 400	1 850	Stone; average, 1 481
7 872.....	2 x 2 ins. = 4 "	7 600	1 150	
7 873.....	2 x 2 ins. = 4 "	4 000	1 000	
7 874.....	2 x 2 ins. = 4 "	7 700	1 925	

A system of testing somewhat similar to the one adopted by the writer was used some years ago by Colonel Thomas Casey upon concrete intended for the Washington monument. The samples consisted of blocks 27 x 27 x 8 ins. thick, and were sheared by means of a cast-iron die 24 x 24 ins., provided in the center with a slot 10 x 10 ins. By means of a cast-iron punch, having a face area of 8.1 x 8.2 ins., and by placing the specimen upon this die, a section could be punched or sheared out through the slot.*

Another, and even simpler, method is to provide stone slabs 12 ins. long, 4 ins. thick and 6 ins. wide. These were tested by placing supports at either end of the sample 6 ins. apart. By means of a plunger, the area of whose face was 30 sq. ins., a section of the specimen between the supports could be sheared out.† It is, evidently, only possible to test such large specimens in an exceptionally large testing machine like that at the Watertown Arsenal.

Transverse Strength.—The determination of the transverse strength of a stone is sometimes important when it is to be used for lintels, sidewalks, culverts, etc., but since such a test involves a number of

* "Report of Tests on the Strength of Structural Materials Made at Watertown Arsenal, 1883," p. 222.

† "Tests of Metals, Etc.," U. S. Ordnance Department, Washington, 1891, p. 737.

factors which must be taken into consideration, the writer has as yet failed to discover a satisfactory method of arriving at the result desired. It seems to him that for all practical purposes a shearing test as just described would be all required.*

Elasticity.—Tests to determine the elastic limit, coefficient of elasticity and "set" are seldom applied to building stone. Probably the simplest method of determining these factors is the best, namely, by the attachment to the testing machine, when making the compression tests, of a suitable apparatus for recording the strains autographically. In this way it is possible to obtain a strain sheet from which the desired factors can be determined readily. A description of the apparatus used for this purpose upon the Olsen or any other testing machine would occupy too much space in this paper.

Porosity.—The porosity or degree with which a stone absorbs moisture is a test of the utmost importance, since, other things being equal, the less moisture a stone absorbs the better it is.

To determine this absorptive power the specimen should be thoroughly dried at about 100° Fahr. and carefully weighed; it must then be soaked for at least 24 hours in distilled water; when removed from the water, the surface allowed to dry in the air and then weighed. The increase in weight will be the amount of water absorbed, and will stand, although not absolutely correct, as an expression of the stone's absorptive power. This test is extremely simple, and when done with care should be entirely satisfactory and practically valuable. The absorptive power of rocks varies very greatly; in general, the sedimentary rocks, limestones, etc., are the most porous, and the eruptive rocks the least. The porosity of sandstones is characteristically exhibited in their manner of drying after a rain; some dry rapidly, while others retain their moisture a long time. Ordinary sandstones absorb from 3 to 10% of weight of water in 24 hours, the harder stones absorb much less.

Action of Frost.—Of all the atmospheric agencies liable to affect building stone frost is the most objectionable. Usually its deleterious effect varies in direct proportion to the porosity; it seems obvious that a stone which absorbs the most water will be the most liable to disin-

* Baker in his "Treatise on Masonry Construction," p. 11, gives a formula for calculating the transverse strength of stone slabs which may be found useful. It must be confessed, however, he has not treated the subject as clearly as might be desired.

tegration due to the expansive action of the ice formed in its interstices.

There are a number of methods in vogue for determining the effect of frost upon stone samples; they all consist substantially of various methods of alternate freezing and thawing, after which the specimens are washed, dried and given a final weighing. The loss of weight is an index of the durability in this particular.

Specific Gravity.—The weight or specific gravity is one of the most, if not the most, important factors in determining the value of a building stone, since by such a test we can also approximately determine its relative density and durability.

Hardness.—The resistance to abrasion or hardness of a stone is, perhaps, as easily determined by the method of Bauschinger as by any other.* It consists essentially in placing a block of stone upon a horizontally revolving cast-iron plate covered with emery, the stone being, of course, held in one position and loaded with weights if desired. The speed of the plate, the size of the specimen and the pressure upon it should, of course, be constant. By weighing the specimen at certain intervals its relative resistance to abrasion may be easily noted.

Destructive Agents.—The destructive influences to which a building stone is subjected may be divided into two general classes—mechanical and chemical. Of the former agencies the most potent in this climate are frost, rain and wind. The degree with which rain affects a stone's durability depends more upon the solvent action of the gases it may contain than upon the mechanical wear of the falling drops. Thus in large cities or in the vicinity of certain manufacturing establishments this solvent action is greatest, and may, in some instances, have a serious result.

The destructive chemical agents are, of course, not as energetic in dry as in wet weather. They are chiefly gases, ammoniacal, sulphuric and carbonic, resulting from the decomposition of organic matter, products of combustion, certain metallurgical operations, etc.

The only way to determine the effect of these gases upon any particular stone is to either subject it for a specific length of time to the direct action of the gases themselves, and noting their action and the stone's loss in weight, or to soak it for several days in water containing

* "Mitth. aus dem Mec. Tech. Laboratorium in München." Unwin, "Testing of Materials of Construction," p. 429.

the alkalies or acids corresponding to each particular gas. By noting the weight from time to time a fairly correct idea of the relative solvent action of the gases may thus be obtained.

Chemical Tests.—The chemical composition of a stone gives but little indication of its practical value, and the time, money and trouble spent in making the analyses is generally used to little purpose. It is, however, sometimes well to know the quantity of silica, lime and alkalies a stone may contain, since, other things being equal, silicious stones are the most durable. A sufficient knowledge of lithology and mineralogy which will enable one to note the relative proportions of feldspar, mica, silica, etc., present, and to determine their specific varieties, is vastly more valuable than dozens of chemical analyses. By means of the microscope the distribution of the various component minerals present cannot only be approximately determined, but the manner in which they are cemented or held together, and their state of decomposition, can be detected without much difficulty.

In some rocks the feldspar and micas are in a more or less decomposed state. When the feldspars are found in such a condition, and appear to be approaching kaolinization, the stone becomes practically worthless for many purposes. Similarly, micas containing large amounts of soda and potash may be very objectionable if they predominate in quantity over the other mineral constituents.

Seasoning.—It has been observed since early Roman times that stone quarried in the warm dry summer months and then allowed to be acted upon by the sun and air for an indefinite length of time becomes somewhat harder. This is due to what is known as the "quarry-water" or "sap" drying out and leaving the stone in a less saturated condition than when it existed in the rock mass. It frequently happens that stones of very good quality are entirely ruined by hard freezing immediately after being taken from the quarry, such being notably the case with some marbles and limestones.* If they are quarried in the warm weather and allowed to become thoroughly dry, the danger is avoided.

This phenomenon is easily accounted for by the supposition that the quarry water carries in solution in some cases carbonate of lime and silica, which is deposited in the cavities of the rock as evaporation proceeds, thus furnishing additional cementing material and rendering the rock more compact.

* Tenth Census of the U. S., Vol. X, Report of the Quarry Industry, p. 27.

"This will also account for the remarkable hardening of some stones after being quarried sometime." "When first quarried they are so soft as to be easily sawed and worked into any desirable shape, but after the evaporation of their quarry water, they become hard and very durable."*

The following bibliographical appendix may be found useful to anyone wishing to pursue the subject further.

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NOTE.—The literature upon this subject appears to be very scanty, and for that reason some references have been given which bear upon it but indirectly. The list is by no means complete, since there are a number of German publications to which the writer has been unable to obtain access.

DISCUSSION.

A MEMBER.—Have you ever tried the interposition of lead plates?

F. LINWOOD GARRISON, Assoc. M. Am. Soc. C. E.—I have never tried lead plates for the reason that all the testimony I have seen is to the effect that they were very objectionable; they produce transverse strains; the lead flows and thus has a tendency to split the rock. I have used plaster of paris in some instances.

J. F. O'ROURKE, M. Am. Soc. C. E.—Do you say the results of the tests of building stone applies as well to artificial stone?

Mr. GARRISON.—No, just natural stone.

Mr. O'ROURKE.—Would it not be true in regard to specimens for crushing—concrete and cement?

Mr. GARRISON.—I cannot answer that question very well. I wrote this paper rather hastily, with a view of bringing out a discussion. My idea was that if we could get the consensus of opinion as to the best method of testing building stone, we could arrive at a better general system of tests. In my opinion it is very essential with all natural stones first to determine what kind of stone it is, of what it is composed, and to understand the mutual of relations of the component elements.

Mr. O'ROURKE.—I mean in determining the strength or resistance to pressure.

Mr. GARRISON.—I have no doubt the same methods would apply; only a microscopical test would not be so essential, or, in fact, at all necessary. I see no reason why there should not be in general the same tests used.